

## Practical Examination of the Corrosion Resistance of Light Alloys

By G. O. Taylor

*Corrosion problems are frequently encountered in connection with the use of light metals and the need for conducting tests to determine corrosion resistance of a particular alloy under service conditions is of great importance. Practical methods for the examination of corrosion resistance of light metals, described in this article, provide workers with a testing technique which can be standardised to produce reliable results.*

CONTINUED research into the fundamental causes of the deterioration of metals by corrosion has produced a wealth of theories and contratheories, and, in the academic sense, the problem has become so abstruse and highly mathematical that it is difficult for the average engineer or metallurgist to gain a clear concept of the issues involved. Despite academic controversy, it is possible, however, with the knowledge of a few fundamentals to reduce the corrosion testing of metals to a routine laboratory task no more difficult to conduct than a standardised analysis or mechanical properties determination. This fact is of considerable importance, particularly to the light metal industry, where corrosion problems are, perhaps, more frequently encountered than in other fields, due to the increasing substitution of alloys of aluminium, and of magnesium, in applications where other non-ferrous or ferrous metals have previously been used, and have been proved by precedent.

Although the necessity for conducting corrosion tests in a scientific manner is becoming more widely appreciated, it is unfortunate that there are still workers who regard such a test as implying no more than immersion of a piece of scrap metal, not wanted for any other purpose, in a vessel containing water or salt solution.

Alloys may be evolved that have remarkable mechanical properties, but unless the resistance to corrosion is good, the fields of application will necessarily be limited. In many cases a material has been specified on strength alone, without regard to corrosion factors, and premature failure from corrosion has made the case prejudicial to the industry in general. A knowledge of practical methods for the examination of the corrosion resistance of light metals may, therefore, serve a dual useful purpose—firstly, by enabling the potential user to appreciate the degree of reliance to be placed on claims made for an alloy by requesting details of test procedure, and secondly, by indicating to workers a testing technique that can be standardised to produce reliable results.

### Types of Corrosion

The types of corrosion attack encountered with light alloys can be classed in four main groups. These are as follows:—

(a) *Pitting or Local Corrosion.*—In this type of attack the metal surface becomes "pinholed," but the areas between such pits or "pinholes" often remain comparatively unaffected.

(b) *Uniform Surface Corrosion.*—The metal surface is more or less uniformly attacked instead of at localised spots, as in (a). This type may be exemplified by the

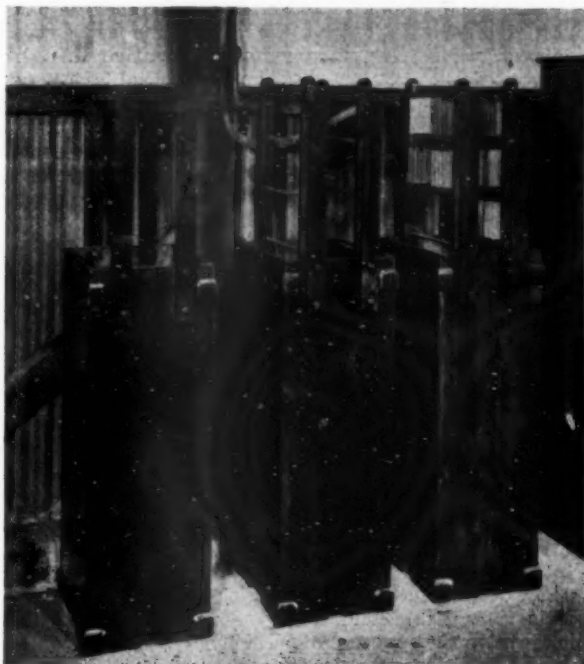


Fig. 1.—Constant-immersion apparatus.

steady dissolution of aluminium in hot alkaline solution, or the dissolution of magnesium in acid solution.

(c) *Galvanic or Electrolytic Corrosion.*—This type of corrosion occurs when differences in potential are brought about by the introduction of a dissimilar metal, such as copper or brass, into contact with light alloy. The action on the light metal is most often in the form of intense pitting or furrowing in the immediate vicinity of the "foreign" metal.

(d) *Intercrystalline Corrosion.*—In this form of attack the surface of the metal may often appear comparatively unaffected, but the action penetrates from the surface downwards into the core of the metal along grain boundaries. It is of interest that this type of action has not yet been detected in the magnesium-base alloys of the "Elektron" type.

A particular type of attack does not necessarily occur alone, and some metals may exhibit combinations of the various forms.

### Effects of the Different Types of Corrosion

Having described the types of corrosive action that the worker may be called upon to recognise, a brief review linking cause and effect, is necessary to enable the possible changes that may be brought about in the condition of the metal to be sought for and determined where it may be necessary by the nature of the proposed application.

(a) Pitting or "pinholing" corrosion may cause a loss in tensile strength and elongation disproportionate to the loss in weight that may be determined. A few pittings of appreciable depth may give rise to a loss in weight much less than numerous small "pinhead" depressions, but the weakening effect in mechanical properties, particularly elongation, may be the more marked in the metal showing the lesser loss in weight. This effect is particularly noticeable in light alloys of the high-tensile type, and the type of pitting may also greatly affect fatigue strength.

(b) Uniform surface corrosion is less harmful, in general, than localised attack. The even reduction of metal thickness obviously reduces the strength in terms of the original by reason of the diminished cross-sectional area, but for a given loss in weight the loss in mechanical properties is at a minimum.

(c) Galvanic or electrolytic corrosion is, by reason of its severely localised action, one of the most serious types of attack, but at the same time can, with observance of a few fundamentals, be greatly retarded, or completely eliminated. The mechanical effects of such action can be very serious. For instance, if thin aluminium or alloy sheet is fastened with, say, brass bolts, the sheets around the bolt heads may be completely perforated in a comparatively short time in the presence of salt-water, and the entire assembly weakened to the point of mechanical collapse. Even in less extreme cases, the concentration of vigorous attack at localised areas can lead to loss in strength.

(d) Inter-crystalline corrosion is perhaps the most damaging of all from the point of view of deterioration of mechanical properties, since it proceeds unseen by the naked eye. With other types of attack, the degree of damage can, to some extent, be gauged by visual examination, but inter-crystalline action, proceeding as it does to produce loosening at the grain boundaries with little surface effect, is dangerous because it may be present to cause serious embrittlement and loss in strength without being suspected.

### Corrosion Testing Methods

Methods for examining the corrosion resistance of metals can be classified into two main sections: (a) Laboratory investigations; (b) Field tests. Field or service tests, which involve the exposure of specimens under the natural corrosive conditions experienced in actual applications are, in general, more accurate in ultimate result and more easily interpreted than laboratory tests. The main disadvantages of such tests are that frequently it is not possible to arrange for personal supervision, while the investigator must be prepared to wait for months, and sometimes years, before results are available. Laboratory investigations can give results in much shorter time, and can, in almost every case, accurately forecast the behaviour of an alloy or discriminate between a choice of alloys for any particular application.

Unless the investigator has some considerable knowledge of the behaviour of metals under service conditions, it is, however, often not possible for the results achieved to be translated into terms of life in actual application with any degree of accuracy. This, however, does not affect the "mathematical" forecast achieved in laboratory testing, if due regard has been given to emulation as nearly as possible of service conditions in the tests undertaken.

Probably the most useful type of laboratory test for obtaining an evaluation of the resistance to corrosion of a light metal under natural conditions, as distinct from chemical conditions, is that involving spraying, dipping or

constant immersion in a salt solution. A test of this description will enable an evaluation to be made of the resistance to sea-water, marine atmospheres and town atmospheres, but will not yield any indication of how the metal will react to chemical reagents. For instance, an aluminium alloy high in copper content will suffer corrosion in such a test, but will be relatively unaffected by the hot fatty acids encountered in oil processing. Such a test, therefore, can only yield indications in the specific directions mentioned, and cannot be used for estimating the performance of a material under other and frequently unrelated conditions.

Since the salt-water test is generally regarded as the "standard" method of determining the resistance to corrosion of light alloys under "natural" conditions, and is, perhaps, the most widely known and used method, it will be described in some detail.

As previously mentioned, however, it must be appreciated that such a test will not forecast behaviour under *any* conditions, and where a specific requirement is called for, such as, for instance, an alloy for making castings to handle, say, acetic acid or hot fatty acids, then a specific test is required, using these corroding agents, and the method in which it must be carried out can only be determined by the investigator with knowledge of the case.

The various types of salt test will enable the following determinations to be made:—

(a) Comparison of one alloy with others, or with reference to their relative resistances to surface attack. The result is mathematically expressed in terms of loss in weight of metal per unit area, and visual observation can be made of the type of corrosion to be expected.

(b) Determination of the effects of sea-water corrosion on the mechanical properties of light alloys.

(c) Determination of the relative efficiencies of applied protective coatings.

(d) Investigation of electrolytic corrosion, particularly as applied to light metal structures for marine uses.

### Testing Equipment for Spraying, Dipping and Constant Immersion in Salt Solution

The preparation of the specimens for the corrosion testing apparatus demands considerable care if reliable results are to be attained. Before the methods recommended are reviewed, however, it is proposed to describe some types of testing apparatus in order that the worker may appreciate certain requirements of such equipment.

The first fundamental need is to ensure that the equipment is itself proof against corrosion! It will be appreciated that since the testing apparatus is itself constantly subjected to severe corrosive conditions it must be corrosion-proof, otherwise frequent renewals and constant maintenance attention will be necessary, not to mention the possibilities of errors being introduced through contamination of the salt solution with corrosion products of other metals.

The second requirement is that the equipment must be so designed that the specimens under test can be so supported that there is (a) no contact with each other, (b) no dripping from one specimen on to another, (c) no dripping from metallic parts of the equipment on to the specimen, and (d) no contact of the specimens with metallic parts of the apparatus.

The third, but not the least important requirement, is that the human factor should be eliminated from the actual test as far as possible, the apparatus itself automatically to provide equal corrosive action on each test specimen.

With these essentials in view, the three types of apparatus described hereafter were evolved by the author in the Technical Department of the Birmingham Aluminium Casting (1903) Co., Ltd., to whom acknowledgment is due for permission to publish the details and illustrations.

### Constant Immersion Apparatus

The apparatus illustrated in Fig. 1 was built for a cost of shillings only. The containers to hold the salt solution are ex-submarine accumulator tanks of solid ebonite, and are of very stout construction. The tanks were drilled to support, with bolts, a varnished wood superstructure. This was designed to take two or more varnished wood specimen-holding racks, each of which had four  $\frac{1}{4}$  in. iron rods covered with rubber tubing, as shown. Specimens for test are threaded on to a glass rod and spaced from each other with small tubes of ebonite. The assembled specimens are held in position on the rubber-covered iron rods by means of rubber bands round the ends of the glass rod.

In such a tank it is possible, with a minimum of space, to test as many as 80 specimens simultaneously, and they can all be withdrawn in a few seconds and supported, as illustrated, while visual examination is being made.

While primarily built for large-scale constant immersion tests, the apparatus may also be used for an intermittent wet and dry test, in which case the racks are dipped into the solution three times a day and afterwards left to drain in the suspended position. If the apparatus is used for this purpose, the rows of specimens should be limited to two each side and the test pieces on the lower rack should be well staggered with reference to those on the upper, so that dripping does not occur during draining times from the top specimens on to the bottom specimens.

An apparatus of this type will give long service without attention, as the materials of construction, being practically non-metallic throughout, are impervious to corrosion.

### Sea Spray Apparatus

An apparatus for testing light alloys in a fine "sea mist" is difficult to construct so that it will work for weeks, or months, if need be without attention other than replenishment of the salt solution. Two sea-spray tanks are illustrated in Fig. 2. The smaller was of stout wood construction, and was lined on the interior with bituminous enamel applied hot and allow to set. This apparatus began to leak badly after 18 months of service, but the experience gained was such that it enabled the design of the larger tank, which gave no trouble and required no maintenance attention after three years of constant use. As will be seen

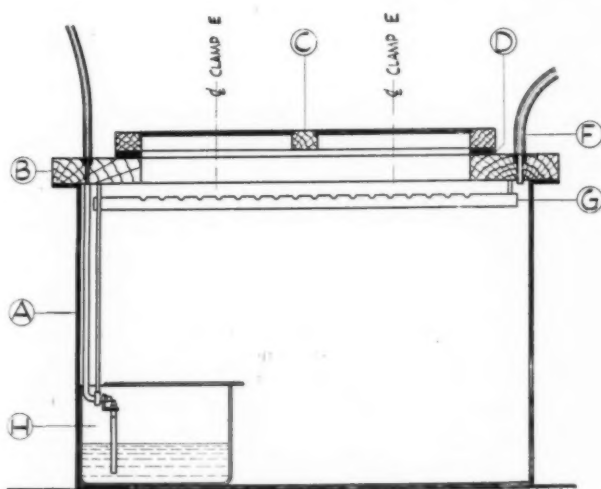


Fig. 3.—Section of one of the salt-spray tanks.

by reference to the sectional view in Fig. 3, the tank was a standard rubber-lined steel tank, 3 ft. long  $\times$  2 ft. wide  $\times$  2 ft. deep, such as can be obtained from suppliers of electroplating equipment. The lip of the tank was drilled to take the hardwood framework B, which was bedded



Fig. 2.—Salt-spray apparatus.

down on mastic and held in position by wood screws passed in from the underside of the lip. The lid C was of hardwood construction, and was furnished with two large observation panels in  $\frac{1}{4}$  in. plate-glass. The underside of the lid was covered with  $1\frac{1}{2}$  in. thick sponge rubber D fastened to the woodwork with waterproof adhesive. Quick action clamps E were provided so that the lid could be detached in a few seconds. Pressure release and exhaust into the open air outside the laboratory were provided, in the manner shown, by three lengths of rubber hose coupled to glass tubes inserted in the wood frames with rubber bungs. The specimen support racks G were of varnished hardwood, scalloped as shown, and held by rubber-covered steel rods passing up through the main frame to provide external adjustment for varying the height inside the tank.

The sea-mist was provided by the arrangement shown in detail in Fig. 4. The adjustable jets were made from "Tufnol" and the assembly held in position by steel rods covered with rubber tubing and passing up into the tank frame. The glass tank H was baffled with  $\frac{1}{4}$ -in. plate-glass so that the salt-water solution atomised at the jets was used up only very slowly, since while very finely dispersed "fog" was released into the tank the majority of the atomised solution fell back into the reservoir to be used again. An air supply at 3-6 lb. per sq. in. pressure, after passing through an air filter, was ample to retain a complete "fog" atmosphere throughout the tank.

Specimens are hung on glass hooks passing over rubber-covered steel rods resting on the scalloped supports.

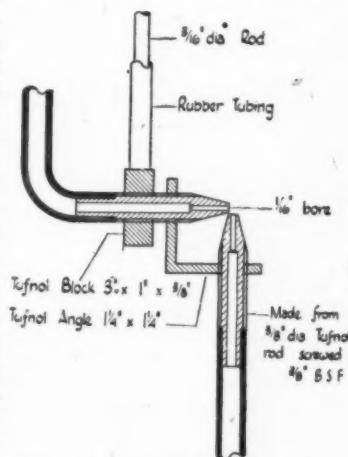


Fig. 4.—Arrangement for producing sea-mist.

Replenishment of 3% sodium-chloride solution in the feed tank need only be carried out every two or three days, even with continuous duty, and it is only necessary to remove condensed solution from the bottom of the main

tank every month. The inert nature of the materials of construction ensures that trouble-free service is attained, and with 3% sodium-chloride solution no jet-clogging has been observed.

*To be continued.*

## Preparation of Test Bars

By Bernard Thomas, F.Inst.P.. F.Inst.F.

*Practical difficulties are sometimes encountered in deciding the form and thickness of test specimens. Some experiences are discussed and variations cited.*

WHERE physical tests are required in the heat-treatment of drop-forgings and stampings, it is customary to have test pieces representative of the ruling thickness. In many cases this is a reasonably satisfactory procedure, and either a length of the original billet or bar may be used direct, or, alternatively, forged down as may be necessary in order that the thickness, or diameter, may equal that of the average dimension of the forging.

There are times, however, when the phrase "ruling thickness" may be somewhat ambiguous, inasmuch that some of the work requiring treatment may be of a flat, or plate, character, with quite substantial lugs or bosses at certain points. It becomes a moot point in such instances to decide whether to follow the plate thickness as far as possible, in order to avoid the forgings being harder than the test piece, although treated together, or whether to lean more in the direction of the size of boss or lug, so as to obtain better information regarding whether good impact figures have been there obtained.

The main object of this note is to draw attention to the point that plate forgings of the type described may be stamped from stock metal of a dimension which requires a fair amount of "drawing down" in order to conform to test-piece dimensions as regards thickness or diameter, and that such work on the stock, unless dealt with carefully, may easily give rise to serious difficulties.

Theoretically, one would expect superior physical results from a test piece reasonably forged, to one which had been cut merely from a length of billet, in the same way that a forging should be superior to a machined part of the billet. In practice, however, this is not always the case as the amount of forging has an important bearing in this connection, since the metal may easily be "over-worked" to an extent that inferior physical test results are obtained.

Meeting with a short cycle of poor Izod impact figures on steel to specification 4811, the writer investigated the matter and found that while the test bars were reasonably representative of the ruling thickness involved, the forgings were of the plate-plus-boss character described earlier, and, in consequence, to reach the required diameter of approximately  $\frac{3}{4}$  in., considerable hammering had been necessary to reduce the test piece to this size from the original stock, owing to the size of the latter called for to provide enough metal for the forging in the dies.

It was natural that the test piece should have been drawn down under the dummy stamp of the pair used for the forgings, and being only a 5-cwt. head a considerable number of blows had been necessary, with the result that the average area of the "flats" on the surface was, roughly, one-tenth of a square inch, measuring something like  $\frac{3}{4}$  in. long and  $\frac{1}{4}$  in. wide in irregular fashion.

Treated with the forgings in correct manner, Izod impact values of some 20/30 ft.-lb. were frequently obtained from such test bars, as compared with the specification requirements of 40 ft.-lb. minimum (concessions ignored). Naturally, the usual steps were taken to rectify conditions, such

as soaking time, quenching more promptly after tempering, increased tempering time, etc., but beyond the odd units of improvement it was obvious that something was radically wrong.

Examination of the actual forgings showed them to be extremely satisfactory, yielding in addition to the other physical requirements impact figures of 55/60 ft.-lb. By introducing normalising between forging and quenching the test bar, some improvement was possible, although still not reaching the forgings level, and it was felt that when it is necessary to "nurse" the latter separately from the work involved, it is time to call a halt and take fresh bearings.

The fact that improvement was yielded by the intermediate normalising was in itself an indication of "over-work," necessitating that treatment to bring about in some measure rehabilitation of the grains affected. It does not suggest lack of soaking time prior to quenching, as exaggerated times for the latter had not been able to bring about the improvement wrought by the double treatment. Thoughts were, therefore, turned next in the direction of method of production.

Test bars were tried off original stock, which gave impact values exceeding the minimum specified, and, consequently, the next step was to produce test pieces with the minimum of forging. As a result of this, sections were roughly drawn down from the billet to  $1\frac{1}{8}$ - $1\frac{1}{4}$  in. square, no attempt being made to square the corners, so that, in consequence, the latter were practically Gothic in character. These pieces, although having a cross-sectional area of more than three times that of the smaller ones, responded to direct quenching in admirable manner to yield figures equalling those on the actual forgings.

As a result of the brief investigation, roughly forged test bars are now employed wherever possible, and with such, on steel to 4811 specification, one may expect to average impact values of from 70/90 ft.-lb.

The writer trusts that he will be excused employing terms familiar in the trade, but offers the plea that by their use such readers as may find value in perusing the matter will find them more expressive, and therefore easier of assimilation.

### The Nickel Bulletin

The November-December issue of *The Nickel Bulletin* includes lengthy abstracts of papers contributed to a symposium on electroplating, and recent work on the influence of nitrogen in stainless steel, both of American origin. Other abstracts deal with hardenability testing methods, effect of cooling practice on case-hardening steels, influence of alloy elements on the critical points of steel, and transformation structures of carbon and alloy steels.

Copies of *The Nickel Bulletin* may be obtained free of charge from the Mond Nickel Company, Ltd., Grosvenor House, Park Lane, London, W. 1. Individuals are asked to state the name of their firm, or otherwise indicate the nature of their interest.

# METALLURGIA

THE BRITISH JOURNAL OF METALS.  
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## The British Iron and Steel Industry

*A vital industry involved in the problem of production is the iron and steel industry, and in this critical emergency it has been remarkably successful in meeting the ever-increasing need for iron and steel to forge the weapons that will ultimately enable our Forces to effect a successful conclusion to hostilities. Production figures cannot be given, but it is safe to say that they exceed any previous high level.*

**D**URING the years 1931-5, when this country was in the throes of a severe industrial depression, certain sections of the Press were very critical of the efforts of the iron and steel industry. In addition to imputations of inadequacy or inefficiency, the integrity of the industry was at times questioned, and the assertion made that reorganisation was unnecessarily delayed. We always considered these criticisms to be unfair, and to have been uttered by those unfamiliar with the problems the industry was called upon to face after the last war. It is a remarkable fact, however, that since the outbreak of the present war no such criticism has been levelled at this industry, although certain sections of other industries have been severely criticised. Undoubtedly, there has been some grumbling, due mainly to delays in obtaining supplies of iron and steel, but generally the opinion is expressed that the iron and steel industry has and is contributing very substantially to the success of Britain's war.

The success of this industry is due largely to the foresight of its executives in the promotion and carrying out of reorganisation schemes during the few years preceding this war. Many of the schemes were put into operation when the industry was experiencing considerable depression, when great courage was necessary to bear the burden of expenditure the schemes involved. Fortunately for the country at this critical time, executives of the iron and steel industry retained a quiet confidence, even in the most depressing times, and proceeded to reorganise, modify, and equip these works in the sure knowledge that this basic industry would be required to meet a growing demand for steel. Although their energies were directed primarily to requirements for peace-time developments in trade and industry, the value of the work done in meeting the present emergency cannot be overestimated. That the foresight and energy of the industry's executives was not misplaced is indicated by the remarkable manner in which the growing demand for iron and steel has been met. It is true, of course, that much steel is imported, this, however, is due to abnormal demands far in excess of the capacity of the plants producing in Britain, but when production figures become available for publication it is safe to say that they will exceed anything previously achieved in this country.

In peace time the basis of prosperity is a wider demand from all steel-consuming industries and the increasing use of steel for a wider range of purposes, but for a country at war it is a vital factor, particularly in the highly mechanised modern warfare. And, just as progress in the industry to meet peace-time demands is largely dependent

upon research, so research is necessary to meet the new requirements promoted by war conditions. It has been necessary to make modifications in practice from the initial smelting of ores to the various finishing of the steels, and careful investigations have been necessary to achieve the best results and the maximum production. Blast-furnaces have been more heavily burdened and the tendency has been towards fewer and more standardised compositions of pig iron. The same is true of the manufacture of steel, largely as a result of a special committee appointed by the Ministry of Supply. This Committee, with Dr. W. H. Hatfield as chairman, has decided that industry generally, inclusive of the armament industry, can be adequately served by a very substantial reduction in steel specifications, in fact, to 58 standards. At first glance this number would seem to be high, but when it is realised that, before the war, there were some 2,000 steel specifications the reduction achieved is a very worthy effort.

Normally, the results of research work come slowly to fruition, but in this time of emergency efforts are concentrated on the application of developments without delay, since the major amount is work naturally concerned with the more efficient manufacture and use of the products of the industry. Much of the work done during the war cannot be published, but it should be noted that, in addition to manufacturing improvements and developments in certain alloy steels, attention has been given to the protection of steelwork, of which the report to the Corrosion Committee of the Iron and Steel Institute, discussed elsewhere in this issue, is an example. This work is of special importance in the present national emergency, when it is essential that all protective materials should be used to the utmost advantage. Another aspect of protection, dealing with phosphate pre-treatments for iron and steel, is also discussed at some length.

In addition to technical progress and despite war-time difficulties encountered by the industry, considerable strides have been made during the past year in the improvement of plant and equipment, with a view to increasing the effort to meet the requirements of the Forces. In this latter aspect electrical engineering has contributed, and there has been considerable activity in the electrical equipment of rolling mills. A good deal of work has been undertaken

in the modernising of old rolling mill installations. In one case, reported by British Thomson-Houston Co., Ltd., this involved a new screw-down drive and new main control equipment for a large reversing mill driven by a motor with a peak rating of 15,500 h.p. at 48-96 r.p.m. The

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

screw-down motors are supplied from three-winding D.C. generators which enable a very high maximum screw speed and rapid screw movement for small adjustments to be obtained, together with inherent limitation of stalled torque of the screws. The employment of the Ward-Leonard principle also gives a high operating efficiency and low maintenance, due to the elimination of heavy starting contactors and resistances. The main drive control equipment displaces an old control equipment, which has given good service for over 20 years.

An interesting rolling mill auxiliary built during the year is an oxy-acetylene descaling machine. The electrical equipment comprises two 20 h.p. mill type motors, with Ward-Leonard motor-generator set and control equipment. Rolled billets from the cogging mill are each passed through this machine, in which the flame jets remove surface defects prior to further rolling. A wide range of speed is necessary to enable the operator to regulate the amount of material removed per pass, and for this purpose the drive is designed so that the speed of the billet through the machine is capable of accurate control.

Numerous mills for special alloys have been modernised or replaced. One plant is reported by Metropolitan Vickers Electrical Co., Ltd., in which the electro equipment controls a 400 h.p. reversing slip-ring motor for the main mill drive operated in conjunction with two slip-ring live-roller motors for the front and back rolls. All the machines are controlled by a single master controller of mill type. In addition, control is provided for the shear drive and the shear table motors.

Another equipment for the rolling of special alloys covered six sets of 100 h.p. mills, which are grouped in threes, so that one group can be run as a tandem mill, while the remainder operate as finishing mills, or the tandem mill switched over to individual running if desired. Control of these mills is on the Ward-Leonard principle, with piston grip master control switches mounted conveniently for the operator. For tandem running, each mill is first run up to speed on its individual control switch, and the selector switch is then thrown over to the tandem position, which puts the three machines under the control of one master control switch.

Considerable attention has been given to tube and shell plant and for shell of 6 in. and upwards in diameter, the piercing and drawing method is generally applied in this country. By this method suitable billets, thoroughly soaked in a pit furnace, are pierced in a press to produce the hollow body. The pierced billet is then moved to a horizontal draw-bench, in which they are pushed through several dies in order to lengthen the body and reduce its wall thickness. Often further heating is necessary to facilitate the final drawing operations to obtain the proper shell dimensions. This method is being applied to some extent in the manufacture of torpedo bodies, for which purpose it is proving quite economical. In one plant engaged on this work a 5,000-ton billet piercing press is installed, and the main horizontal draw-bench operates at a working pressure of over 3,000 lb. per sq. in. A number of smaller push-benches, however, have been put into operation during the year, and mention may be made of the electrical equipment installed for operating a 700 h.p. push-bench. The main motor, although rated at 700 h.p., is capable of normal peaks of 1,400 h.p. and emergency peaks of 1,800 h.p. The Ward-Leonard generator is driven by a synchronous induction motor. The mill speed is controlled by the generator field up to 300 r.p.m., and beyond that by motor-field control.

#### Scrap Iron and Steel

In addition to the efforts made to increase the use of domestic ores in order to save transport overseas, the need for a continuous supply of scrap iron and steel is ever present. It is well known that a large proportion of the material used in the manufacture of steel is scrap metal,

and again overseas transport must be saved by careful scrap recovery throughout the country. The need is urgent. It is noteworthy that a national effort has been put into operation by the Ministry of Works at the request of the Minister of Supply. It is proposed to sweep the country from end to end of steel and iron scrap, large and small. As a result of this national drive, it is hoped to supply the industry with 40,000 tons of scrap per week; this will not only need careful and energetic organisation, but also the active co-operation of all who can in any way contribute to its success. In addition to the normal supplies of scrap which are available through scrap merchants, who will carry on their normal business, the campaign embracing the national drive will fall roughly under three heads:—

- (a) A national survey of all idle iron and steel in lots of over 3 tons in any one place. This survey is being accelerated, and it will be made compulsory to disclose all such metal.
- (b) Clearance of local dumps to which lots of less than 3 tons should be sent as quickly as possible.
- (c) Acceleration of the collection of railings.

Under (a), the national survey, will be included disused pithead gear, bridges, rail tracks and factory machinery, as well as the large accumulations of loose scrap.

Under (b) will be taken the small quantities in yards of all sorts, from small builders and factories with no regular scheme of passing scrap back to the foundries, as well as the scrap turned out by private householders and others. Local dumps will all be cleared, but each village must not think that its own dump will be cleared to-morrow. The dumps are going to be taken county by county, and it may be some months before the turn of any particular county comes along. What we want is a steady, regular flow to the foundries, and that can be secured only if each town and village starts to fill up its dumps *now*, ready for clearing when the foundry needs it. The Ministry asks that the mole-hills should be turned into mountains of scrap, and appeals to the leading men and women in town and village to see that everything is contributed to the war effort. The war machine must be fed.

Under (c) the collection of railings will be continued and accelerated. The Ministry asks for the help of all in this difficult task.

The vital need of this raw material in the manufacture of steel makes it essential to maintain supplies to ensure the maximum production, and no effort should be spared to comply with the request of the Ministry of Works.

#### Iron and Steel Institute

The Council of the above Institute announce that Mr. Walter S. Tower, President of the American Iron and Steel Institute, has been nominated an honorary member; Dr. Andrew McCance, Director of Messrs. Colvilles, Ltd., has been elected a vice-president; Professor J. H. Andrew, D.Sc., of Sheffield University, and Mr. N. H. Rollason, managing director of Messrs. John Summers and Sons, Ltd., have been elected members of Council.

The following have been proposed to take office at the annual general meeting in 1942:—As President, Mr. James Henderson, deputy chairman of the Appleby-Frodingham Steel Co., Ltd., and director of the United Steel Companies, Ltd.; as Honorary Treasurer, The Hon. R. G. Lyttelton, director of Messrs. Guest, Keen and Nettlefolds, Ltd., and of Messrs. Guest, Keen, Baldwins Iron and Steel Co., Ltd.

In pursuance of their policy of collaboration with local societies, the Council have invited the presidents of the Sheffield Society of Engineers and Metallurgists and of the Sheffield Metallurgical Association to become honorary members of Council during their periods of office.

# Phosphate Pre-Treatments for Iron and Steel

By E. E. Halls

*Under present conditions the preservation of iron and steel is greatly increased in importance, and any means of achieving this end cannot be ignored; the phosphatising processes discussed in this article are therefore of immediate interest; they are technically developed and controlled processes and successfully perform their function.*

**C**OSLETTISING, Parkerising, Bonderising and Granodising are familiar names among others that refer to phosphate rust-proof coatings for iron and steel work. The patents covering the Coslett processes date back to 1906 and refer to the treatment of articles in a solution of phosphoric acid saturated with ferrous phosphate. Similarly, the early Parker processes used a solution of phosphoric acid containing manganese dioxide. Another method used a 15% solution of calcium hydrogen phosphate. These procedures all employed boiling solutions, immersing the thoroughly cleaned work for periods up to several hours, until a film, slaty grey in colour, porous in nature, formed in intimate union with the work. The latter was then thoroughly washed and dried, and was usually given a further treatment of impregnation with wax, mineral oil, or linseed oil. The term "rust-proof" became rather mis-applied because actually the phosphate film in itself is not, strictly speaking, rust-proofing in nature because, being porous, it is easily influenced by condensed moisture, particularly in corrosive atmospheres, and then produces rust-like deposits with ultimately heavy rusting.

The true value of these coatings as a seating for paint and enamel, with the assurance of adhesion of the latter, and in conjunction with the organic coatings for providing inhibition and prevention of rust spread, does not appear to have been appreciated till a much later date. This failure was no doubt due to shortcomings in the early processes that rendered them unreliable and costly. These objections may be summarised as difficulty in control of the solutions and their uniform maintenance over a period of time, the consequent variations in serviceability of the coatings produced, and the excessive processing time.

This undesirable condition of the order of 15 years ago was corrected by the controlled Parker process, which may claim to be the first fool-proof phosphatisation process established in industry. It was still an immersion process using boiling solutions, and the time factor was still lengthy, being from 1 to 2 hours. Results were, however, assured, the solution being prepared from proprietary chemicals and maintained by additions, and controlled by regular analysis, using a very simple titration method. The cost involved in time and restricted source of supply of chemicals was offset by the certainty of the process in producing the anticipated results.

The value of this process gradually became realised as demands for industrial enamelling grew and rapid processing using air-drying cellulose products was introduced. Cellulose coatings over Parkerising were found to age and embrittle less rapidly than was normally experienced, and they retained their adhesion without developing chippiness and flaking. The next stage was the expansion of the automobile industry, which demands rapid finishing with first-class durability. Immersion Bonderising was the result, closely allied to Parkerising, except times were reduced to about 15 mins. and copper salts appeared as accelerators instead of manganese compounds. Further advances in this field, as well as demands in other industries, refrigerators, typewriters, metal furniture, light electrical equipment, etc., have caused further marked improvements.

Modern Bonderising in the D process enables work to be immersion treated in times from 2 to 5 mins. to give invaluable coatings at least equal to the 15-min. process. Moreover, extending the time to half an hour enables films as thick and sound as the original successful Parker coatings to be obtained. Again, spray methods are available that involve exposure periods of only 1 min. Other similar processes, such as the range of granodising treatments, are also commercially established. The proprietary solutions involved usually contain zinc salts and nitric acid as the accelerating agency.

The modern phosphatising processes are a success, firstly by virtue of their quality merits, and secondly because they are readily manipulable and economic. Ease of control, simplicity of plant, and uniformity of product in conjunction with rapidity of operation mean much to modern engineering. But other features have also been studied. Thus, after the water rinse, a final rinse in a hot dilute solution of chromic acid is given, followed by drying in air, air blast or oven. This chromate treatment adds considerably to the rust-proofing qualities of the coating. Again, work leaves the process with a very light dusty film upon it. This may be ignored, and, in properly controlled processes, will be found to be without effect upon the appearance of the paint or enamel coating. On the other hand, by wiping before enamelling, the protective value of the enamel coating, particularly single organic coats, is still further improved, in fact out of proportion to the cost and effort of the wiping operation. This is consequently a feature to bear in mind when finishing work for very arduous service, or at the other extreme, when costs have to be cut to a minimum and the utmost has to be secured from one-coat jobs.

The attributes of modern phosphatisation processes from the point of view of the quality characteristics imparted to the work treated may concisely be summarised as under:—

1. Provision of a sound key for adhesion of organic coatings.
2. In conjunction with the organic coating, outstanding properties of rust prevention or rust inhibition, as well as positive resistance to rust spread from bared areas that may themselves rust under adverse circumstances.
3. In a manner not clearly understood, but very perceptible in practice, preservation of the characteristics of the organic coating. Thus, "ageing" and embrittlement are appreciably retarded or prevented, and flexibility and adhesion retained. Resistance to mechanical stresses of vibration, flexing, and, most important, of impact, is not merely improved, but rendered positive. Again, resistance to mechanical wear and abrasion, as of that due to one component being forced over another, is remarkably improved.
4. Durability of finishes is increased manifold. The mechanical and physical permanence of paint and enamel coatings are vastly enhanced, and rust resistance accentuated. Consequently—

(a) Work that is refinished periodically requires this reconditioning at less frequent intervals.

- (b) Work that is enamelled before assembly and cannot be refinished during service is given longer life—firstly with respect to visual appearance, secondly, with regard to the destructive influences of rust.
- (c) Longer service is obtained from established finishes.
- (d) Service superior to that of established finishes is obtained with fewer paint or enamel costs.

The intelligent use of phosphate processes, therefore, inevitably leads to an economic saving in consequence of improved serviceability, or from lesser paint consumption, with lower labour costs in its application, or from both of these factors.

5. Protection of or prevention of rust spread from recesses, seams, folds, overlaps and crevices of a like nature that normally are difficult or impossible to safeguard by organic finishing processes.

6. Retention of phosphatising chemicals in seams, folds, etc., unlike the retention of electroplating, cleaning or pickling chemicals, normally cause no trouble from corrosion creep, because, in general, they are rendered innocuous in the chromate rinse and drying-off processes.

7. Incidentally, most modern phosphate processes for iron and steel are not only applicable to alloy steels (tool and magnet steels) and to cast irons, but also to zinc base alloys and to zinc and cadmium coatings of all types without modification to operating conditions other than to immersion times.

The improvements imparted to the finish by phosphate pre-treatment apply to all types of paint and enamel finish and, broadly speaking, to all qualities of medium within the same class. Nevertheless, all who are interested in producing sound finishes make a discerning selection of raw materials. In this way, paints and enamels, primers and surfacers, should be selected on a quality basis, incorporating the following factors:—

- (a) Manipulability in application—that is, suitability for dip or spray application, evenness of film, freedom from runs and bittiness, and proper flow to provide a level coat.
- (b) Economic drying rate, whether air-drying or stoving.
- (c) Proper adhesion, flexibility, freedom from chippiness and flaking.
- (d) Covering and obliterating power.

Cost per gallon is the purchasing agent's measure of value but this must be interpreted in relation to the criteria just set out. Type of finish required and plant available will often dictate the nature of the media employed. Some types are superior to others; thus, in general, synthetics, whether air-drying or stoving, are superior to the corresponding ordinary oil-base products, and these in turn are generally more durable than cellulose media.

Again, the type of finish required, service requirements and value of the equipment or work concerned, will have some bearing upon the finishing scheme adopted. One, two or more coats; the use of a primer and surfacer; filling, final flattening or polishing: all these are just as practicable on phosphatised work as when pre-treatment is not employed. Thus structural work, and inside and reverse surfaces of panels, cabinets and the like need rust-proofing and a neat finish without special artistry, whereas face surfaces require pits and blemishes efficiently filled and flattened, and an attractive uniform finish. In the illustrative data presented herein, finishes have been selected to cover a full range of types without reference to these perfecting operations that have no influence upon the fundamentals involved. The subject can conveniently be dealt with under the following headings:—

1. Process: Complete operations entailed in phosphatising.
2. Plant involved for phosphatising.
3. Durability test data on iron and steel work, with and without phosphatisation.

These will be considered very briefly in sequence.

## Process

Phosphatising involves the following operations:—

- A. Thorough degreasing and removal of swarf and loose dirt.
- B. Where necessary, removal of rust and scale.
- C. Phosphate immersion (or spray) operation.
- D. Water wash.
- E. Chromate immersion (or spray) operation.
- F. Drying off.

Spray processes will be separately referred to as, in these, work freed from heavy contamination is completely processed in a conveyerised system.

Regarding the above preparatory operations, pre-cleaning is to some extent determined by the nature of the work, but also by the plant available. Obviously, the same perfection of cleanliness as is demanded by normal enamelling and electroplating processes is essential, and within limits any of the orthodox metal-finishing department processes can be used. It is important, however, to ensure that all chemical solutions used are completely washed from the work before the latter is introduced into the phosphatising plant, otherwise traces of pickling acid or of alkaline cleaning solutions continually carried over into the phosphatising solution will have a detrimental effect, because they become accumulative and in time upset the balance of the solution beyond the point at which this can be corrected by daily additions. In general, it can be said that all oil, grease, swarf, dirt, rust and scale must be removed.

The simplest industrial method of getting rid of oil is by means of a trichlorethylene vapour degreaser, and if loose swarf and dirt are present the liquor-vapour type of plant is effective and quite sufficient. On large structural work it might entail too large a cleaning equipment to make the latter economic. A simple wipe down with a cloth soaked in solvent, such as solvent naphtha, turpentine or turps substitute giving two such wipes, one to take off the main contamination and a final cleaning one, has proved quite satisfactory. On the other hand, ordinary alkaline cleanses can be used, but as caustic soda, sodium carbonate, etc., are very detrimental if they accumulate in Bonderising solutions because they cause irregular Bonderising, such methods are not recommended. They are all right if fully controlled, and one of the milder alkalies should be used at low concentration—that is, one of the silicate or phosphate base cleaners.

In spray Bonderising, a spray alkali clean is used, but here it can be very dilute and is perfectly controlled by the speed of the chain through the cleaner and through the subsequent water rinses, and by the design of the equipment. Such control is not usually available with immersing methods. If acid pickling is involved then alkali cleaning can logically follow because the same additional operation care to ensure complete removal of pickling acid is also entailed.

Rust and scale, if present generally over the article, is best removed by shot-blasting. On frail work, of course, pickling has to be resorted to. If the bulk of the work is mild steel in good condition, with just an occasional local patch of rust, either this is ignored or cleaned off with abrasive, such as wire brush or emery paper. In the case of the slight black scale produced in spot-welding, it is quite normal to ignore this completely without any detrimental effect resulting.

For the mill scale on structural iron work, if shot-blasting is not available, then thorough cleaning by means of a scratch brush, to remove completely all loose scale, is acceptable. Actually, the phosphate coating takes quite effectively over scale without any detriment, except if the scale becomes detached at a later date it exposes an untreated surface. Again, the phosphate treatment takes satisfactorily over rust, but it has other shortcomings. Firstly, it means that an expensive solution is being used, virtually as a pickle, which is not economic, and secondly

it means that a rough phosphate coating results, together with the fact that all irregularities in the degree of rusting are reproduced in the appearance of the phosphate coating. As a result, more enamel coats with fillings and flattings have to be applied to produce a finish of good appearance. In some cases this does not matter; in others, of course, it does, and economically the procedure is unsound.

Summarising, therefore, a solvent clean should be employed wherever practicable and relied upon entirely. Where the work necessitates it, abrasive blast or wire brush should be used. Pickling and alkali cleaning should only be used where necessitated in special instances. It is pointed out, however, that there are certain relatively rare cases of rolled steel sheets which have peculiar areas which, merely degreased, do not take the phosphate treatment. This peculiarity is, of course, readily corrected by mechanical treatment of shot-blasting, abrasive paper or wire brush, and it is likewise easily corrected by a few seconds' immersion in 50/50 hydrochloric acid pickle. Incidentally, a parallel case occurs with zinc base die-castings, and for some unknown reason some batches of castings, or even some castings in the same batch, fail to take the treatment properly. These are always corrected by light shot-blasting, after which the components readily respond to a 3-min. immersion or short spray phosphate process. Cast iron components should be abrasive blasted.

Regarding the immersion phosphatisation proper, conditions vary a little according to the particular process employed, in particular with respect to time, temperature, and concentration. In exemplification of the processes, pertinent details in the following refer to the Bonderite D process.

The work may be wired, racked or treated in baskets or on hooks through the phosphatising plant, consisting of phosphate immersion, water wash, chromate immersion, and dry off, these operations being carried out successively without delay other than that required for the transfer from one tank to another. Typical times and temperatures are as under:—

Operation.	Solution Temperature. 180°-185° F.*	Immersion Time.
Phosphate immersion ..		Good clean steel work, 2-3 mins. Hot rolled, scaled steel, 5 mins. Cast iron, 3 mins.
Water wash .....	170° F.	Up to 2 mins., according to nature of the load.
Chromate immersion ..	170° F.	15 to 30 secs.

\* (Note.—185° F. is a rigid maximum.)

Work is then immediately dried off. Massive work can be dried by its own retained heat, aided by air blast where necessary. Thin sheet and other light work can be dried off by oven heat, temperature not being critical, but preferably a little above that of any subsequent enamel stoving temperature. Ventilated gas or electrically heated ovens up to 500° F. are satisfactory.

In loading, care must be exercised to ensure that solutions have free access to all surfaces and that articles do not lay flat on one another. Miscellaneous small details may be treated in baskets, and such baskets must be manually shaken at intervals of at least 30 secs. in the phosphate solution, continuously during the water washing, and continuously in the chromate rinsing. Likewise, precautions must be taken to avoid air-locks or pockets that promote uncoated areas, which easily rust before drying-off.

The Bonderite D phosphate solution is prepared from 0.85 lb. of I.M.U. Bonderite Chemical D per gallon of water.

It is maintained to the correct operating strength by periodic additions of "R" Bonderite Chemical as demanded by analysis, and by keeping to constant level by mains water additions to compensate for evaporation. The water wash must be supplied with flowing water to keep the degree of contamination within negligible limits, and this can be covered by routine tests.

The chromate rinse is generally made from 0.005 lb. of chromic acid per gallon of water, but with exceptionally hard waters a slightly higher concentration may be deemed advisable. With such a weak inexpensive solution, additions are not warranted, but complete replacement, say, weekly,

is preferred. The solutions must be kept clean; sludge forms in particular in the phosphate solution, and this must be periodically cleaned. For this purpose the water-rinse tank can be emptied, and the phosphate solution carefully pumped into it, taking the minimum of sludge. The sludge can then be cleaned out of the phosphate tank and heating coils de-scaled. Actually, the daily analytical checks indicate when this clean is seriously required because it corresponds in practice to an unduly high replenishment addition of R chemical being required. After cleaning, the solution is returned to its tank, volume losses made up with water, and the corresponding weight of 1 MU chemical and finally balanced with the R material. This cleaning, on the average, is necessitated once in from 6 to 8 weeks.

The analytical control is simple. A 10 ml. volume of the Bonderite solution is titrated against N/10 caustic-soda solution, using a few drops of 1% phenolphthalein solution as indicator. The titration value in mls. is designated the "pointage," and the solution is maintained at a level of 20 points nominal. For example, a 1,000 gal. capacity vat can be allowed to fall to 20 points, and is then reconditioned by addition of 21 lb. of R chemical per 1,000 gals. for each point below 20. The wash water is not allowed to exceed 0.3 points when tested on 50 ml. of the water. The other types of phosphate solution are similarly maintained.

Most of the modern phosphate processes yield a uniform slate-grey coating, slightly crystalline and porous in nature. If the solution is properly maintained with respect to composition and sludge, only a very fine loose powdery effect, almost imperceptible, is present. A light wipe over with a soft grade of steel wool is effective in further improving rust-proofing properties, although not essential from the enamelling viewpoint.

Phosphatised work should be finished immediately after phosphatising. In the case of work completed at the end of the working day, this may be finished the following day providing it is stored in a reasonably dry atmosphere away from chemical fumes.

#### Plant Involved for Phosphatising

It will be seen from the foregoing that immersion phosphatising involves a unit plant comprising three tanks, for phosphatising, water wash and chromate rinse, each of capacity and dimensions to deal with the size of work to be treated. They can all be of welded mild steel; corrosion and scaling propensities of the phosphate solution demand that this tank should be of heavy gauge. Indicating thermometers are required in each, and these can satisfactorily be arranged in extension chambers from the ends of the tanks. The phosphate solution requires automatic temperature control, but reducing valves on the steam lines suffice for the other two. Heating is by closed steam coil, preferably arranged vertically along one side of the tanks, thus promoting heat distribution readily by convection. The heating coils for the phosphate solution are brass. All tanks can with advantage be lightly lagged to conserve heat, and an outer casing of galvanised iron gives a neat durable finish.

In practice, it is often found that the unprotected iron or steel phosphatising tank fails from corrosion unduly fast. The scale that forms serves as a protection, but the vertical walls below the level of the steam coils, especially in large equipments, may not become scaled and direct corrosion, combined with the mechanical action of the sludge in the lower layer of solution, gradually causes pitting and ultimately pin-holing. If such weak spots are not located by regular inspection and dealt with immediately there is always the danger of loss of valuable solution. A means of protection that has proved satisfactory in practice is the simple one of fixing angle iron around the periphery of the inside of the tank, cementing it in position with pyruma putty. However, the soundest procedure is to employ a hard rubber-lined tank (e.g., Nordac). This has indefinite life with respect to corrosion and is free from scaling troubles, thus easing the maintenance problem.

Plant of this type can be manually fed or operated with a simple electric or air hoist and overhead runway. With the tanks in line, work can systematically pass from one to the next, and the phosphatising tank can be longer than the others in order to cater for the longer immersion time in the phosphate solution. The runway can also pass through the drying oven, and thence to the wiping position prior to enamelling. The oven can utilise any of the usual industrial fuels, but a simple gas-heated plant is satisfactory as temperature control is in no way critical. A double-ended oven with open gas burners in the base and ventilation from the top is acceptable.

Spray treatment involves a conveyerised plant, comprising a series of chambers, one for each operation, fed by an overhead chain. Such plants are economically suitable only when large quantities of components of similar type have to be treated. Work is fed to the equipment in a pre-cleaned condition, but a weak alkaline spray is the first operation on the line, this being essential to "wet" the work and to remove finger marks and other light incidental contamination in order that the rapid spray phosphatising can be efficient. The unit line therefore embodies the following items:—

- (a) Hot spray alkaline cleanse.
- (b) First hot-water spray.
- (c) Second hot-water spray.
- (d) Hot spray phosphatising.
- (e) Hot-water spray.
- (f) Hot chromate spray.
- (g) Rapid drying off.

The plant, therefore, has not only to provide treatment chambers for each of these, but also, for the aqueous treatments, reservoirs with continuous pump circulation for the fluids involved. Quantity and size of work primarily determines the size of the plant, but the phosphatising

provided with stainless steel stand-pipes. The phosphate reservoir tank is likewise hard rubber lined, whereas the others can be welded steel. Again, the pump for the phosphate solution must be of corrosion-resisting steel, with glass-lined valves, whereas cast iron is used for the other sections. To maintain specified temperatures, the reservoir tanks must be lagged. Thermometers are required on the tanks and in the riser pipes, with automatic control for the all-important phosphatising section. The alkali tank requires a weir type scum overflow arrangement, and the phosphate tank has to be sectionalised with screens to keep back sludge. Heating is by steam coils immersed in the tanks, but they must be accessible for easy removal for cleaning and maintenance. The drying oven is usually a single level type, with a hot-air seal at the outlet end, and gas-heated from a separate gas furnace. Alternatively, a camel-back oven is suitable.

The above are only very brief, but salient details of a spray phosphatising equipment. Diagrammatically, it is shown in Fig. 1. If work is suitable for such treatment and available for continuous operation in sufficient quantity, undoubtedly the rapid spray process is the one to adopt. It is economic, rapid, compact, and equally efficient as the immersion method.

### Durability Test Results

Service experience and all forms of accelerated corrosion tests establish the facts presented in the early section of this article to demonstrate the utility of phosphate treatments. Full details of test results to cover all combinations of finish and types of test are beyond the space available. In this connection an endeavour has therefore been made in the attached figures to present test results diagrammatically, so as to obtain at a glance a fair representation



Fig. 1.—Arrangement of plant for spray phosphatising, conveyer (overhead chain) enters at A, leaves at B.

C. Entry vestibule.  
D. Spray alkali degrease.  
E. Phosphate spray.

F. Chromate spray.  
G<sup>1</sup> to G<sup>6</sup>. Drain, back and baffle sections.

H<sup>1</sup> to H<sup>2</sup>. Water sprays.  
J. Gas-fired oven.  
L. Gas combustion furnace for oven.

K<sup>1</sup> to K<sup>6</sup> Liquor tanks, steam or oil heated, to feed sprays.

chamber is the most critical feature that in turn decides the conveyer speed. The time in this zone is of the order of 1 min., with a temperature of 170°–180° F. Plant has to be arranged with connecting tunnels between zones fitted with deflecting baffles and drain slopes to avoid the various continuously circulated solutions from mixing and contaminating one another. The conveyer track has to be protected from direct spray with chemicals. An ordinary conveyer chain of simple construction, and having self-lubricated graphite ("morganite") bearings is employed. Temperatures and distances have to be controlled in relation to one another, so that work does not partially dry-off between zones. Sprays, arranged on vertical stand-pipes, must completely "flood" the work with "sheets" of liquor, and those on opposite sides of the plant must not operate against one another and thus cause loss of efficiency. The spray nozzles are brass, and of the turbo type (e.g., Binks) and number and position are important and determined from experience and by experiment; some adjustment on them is therefore desirable.

The spray tunnel is usually of galvanised iron construction, with galvanised iron stand-pipes, except for the phosphatising section, which is hard rubber lined and

of the relative merits of enamel finishes on iron and steel with and without phosphatising.

The test referred to in all cases was the standard salt-spray test, in which the specimens were exposed to the atmosphere produced by atomising 20% salt solution with compressed air. To this end, the specimens were obliquely positioned in a cabinet in the base of which the atomiser was fitted and the mist produced rose up through glass baffle plates. The test was conducted at ordinary laboratory temperatures and one day test period included the eight-hour working day with the atomiser operating and the specimens left in the spray-laden atmosphere for the remainder of the day. Before starting each day's test, specimens were washed in flowing water and dried on a soft cloth.

The test results presented may be regarded as average rather than individual, and to be strictly comparable by virtue of carrying out the tests simultaneously in order to obtain identical conditions. For convenience, a concise summary of the finishes covered by the tests is given in Table I, from which it can be seen that ordinary air-drying oil enamels, stoved synthetic and air-drying cellulose enamels were all employed on specimens with and without

bonderising. Table II briefly summarises the characteristics of the various enamels employed.

In the accompanying diagrams an attempt is made to classify the extent of deterioration of the specimens during test. The rate of deterioration would naturally vary according to the nature of the specimen and the perfection of the base material. For this reason structural ironwork is covered, and any prominences, sharp corners would be expected to show first signs of failure. In the case of sheet-work, the components tested included seams and spot welds which again gave lines of relative weakness. Additionally, a scratch line was cut on all specimens through the enamel coating to the base material before test, in order to encourage a breakdown and to study the rate at which it spread from this line beneath the enamel coating.

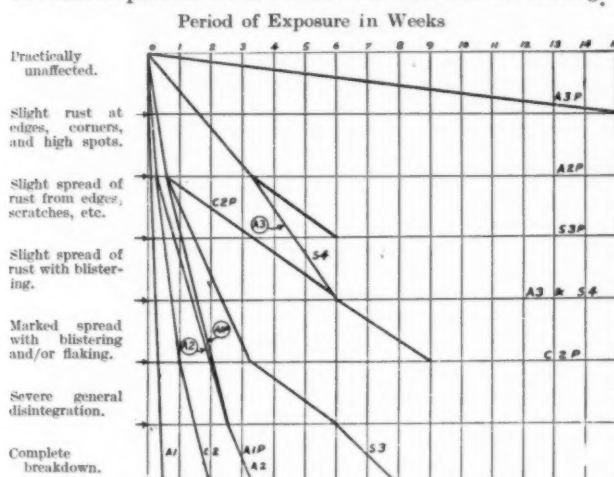


Fig. 2.—Results of salt-spray exposure, structural iron specimens. For finishes see Table I.

TABLE I.  
CONCISE SUMMARY OF FINISHES COVERED BY TEST CHARTS.

Ref. No.	Type of Enamel.	Chemical Pre-treatment.	Enamel Coats.
A 1	Air Drying Oil Enamel	Without phosphatisation.	One coat direct.
A 2			Two coats direct.
A 3			One coat over red oxide primer.
A 1 P		With phosphatisation	One coat direct.
A 2 P			Two coats direct.
A 3 P			One coat over red oxide primer.
S 1	Stoved Synthetic Enamel.	Without phosphatisation.	One coat direct.
S 2			Two coats direct.
S 3			One coat over red oxide primer.
S 4		With phosphatisation	One coat over zinc chromate primer.
S 1 P			One coat direct.
S 2 P			Two coats direct.
S 3 P		With phosphatisation	One coat over red oxide primer.
S 4 P			One coat over zinc chromate primer.
C 2	Air Drying Cellulose Enamel	Without phosphatisation.	Two coats direct.
C 2 P		With phosphatisation	Two coats direct.

TABLE II.  
PROPERTIES OF FINISHING MEDIA EMPLOYED.

No.	Type.	Medium.	Physical.		Chemical.		Drying or Stoving Times.
			Specific Gravity at 25° C.	Viscosity Centipoises at 25° C.	Total Solids, %.	Volatile Spirit (Loss 3 hrs. at 110° C.) %.	
1	Air Drying Oil.	Red Oxide Primer.	1.623	510	57.5	42.5	12 hours air drying
2		No. 33 Blue Grey Enamel	1.260	1,000	69.0	31.0	8 hours air drying between coats 48 hours after final coat before packing.
3	Stoved Synthetic	Red Oxide Primer	1.510	420	69.5	30.5	1 hour at 250° F.
4		Zinc Chromate Primer	1.080	210	44.5	55.5	" "
5		No. 33 Blue Grey Enamel	1.055	215	50.3	49.7	1 hour at 250° F.
6	Cellulose	No. 33 Blue Grey Enamel	0.991	875	32.5	67.5	4 hours between coats. 48 hours before packing after final coat.

Consequently, it will be seen from the diagrams that the grading of deterioration has been classified into (a) virtually unaffected, (b) slight rusting at edges, prominences, seams, etc., (c) increased rusting, (d) spread of rusting with blistering or flakings, (e) marked spread from these areas, (f) marked general deterioration, and (g) complete breakdown.

Fig. 2 refers to structural ironwork, and Fig. 3 to sheet-metal work. All work was processed along the lines indicated, properly cleaned to free it from oil, grease, dirt, rust and loose scale. The channel work was not shot-blasted, but left in the scaly condition. Phosphatisation was by immersion for 5 mins. Sheet work included spot-welded seams and folds. It likewise was not abrasive blasted; phosphate immersion time was for 3 mins.

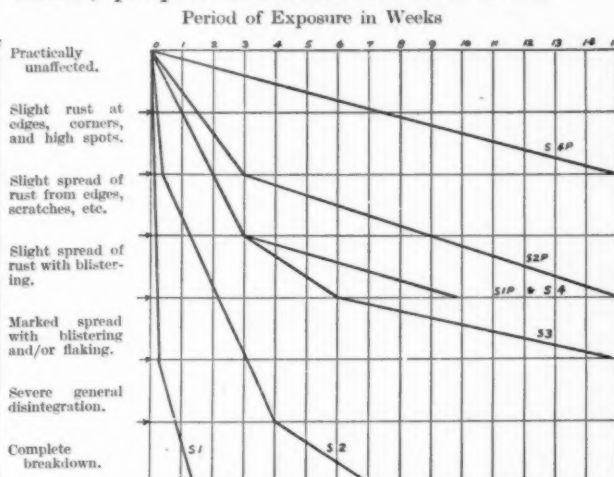


Fig. 3.—Results of salt-spray exposure of sheet mild steel specimens. For finishes see Table I.

Referring to Fig. 2, it can be seen that, under the test conditions obtaining, the following facts emerge for the finishes on rough ironwork:—

- One or two coats of air-drying enamel on phosphatised surfaces show exceptionally good rust-proofing properties, whereas without phosphatisation, both these finishes are relatively short lived.
- Red oxide primer with one coat of air-drying enamel in the absence of phosphatisation shows marked improvement, but still falls short of the two-coat finish on phosphatised surfaces.
- Red oxide primer and one coat of enamel, both stoved, does not show quite the same merit as the air-drying oil enamels on this class of phosphatised base metal, but is much superior to the same finish without phosphatisation.
- Zinc chromate primer and stoved enamel is much superior to the two-coat stoved finish that includes a red oxide primer.
- Cellulose finishes are inferior to the oil or stoved finishes, but phosphatisation imparts the same benefits.
- Phosphatisation and one coat of enamel fails under this test, but only due to general "point" rusting at high spots in the base material.

Fig. 3 bears out similar results, but emphasises that the better surface condition of the base material causes generally a better performance, this being more marked with phosphatised samples. Moreover, it brings a finish comprising phosphatisation and one coat into the foreground as an exceedingly durable job.

Fig. 4 is included to show the value of the final chromate rinse in improving performance, and also to show the value of the "wiping" operation. It is otherwise self-explanatory.

Although some of the advantages of the phosphatised specimens in single or double coatings are thus made quite evident, the vigorous nature of the salt-spray test does not bring out to the full the property of retention of flexibility and adhesion of the enamel coatings. It shows that special inhibitive primers, preferably containing zinc chromate pigment, but of intermediate value with red oxide pigment, must be used if phosphatising is avoided and rust spread is to be retarded. All normally employed paint and enamel coatings gradually age and become harder and more brittle, and generally deteriorate with respect to impact; also expansional and contractional forces tend to reduce adhesion. The unique keying properties of the phosphate coating present from the outset a better anchorage than any other known method of surface preparation and additionally the phosphate coating appears to exert some delaying influence upon ageing. This can be seen from relatively mild humidity tests or from intermediate conditions of open atmospheric exposure. For example, a series of test specimens corresponding to those represented in the salt-spray test, were exposed to a cyclic humidity test, in which the samples were suspended in a closed cabinet provided with means of varying temperature and humidity. Temperature was controlled during the day to 55° to 60° C. by means of electrical heaters and an external resistance. Humidity provided by trays of water in the base of the cabinet was about 70% during the day. The test cabinet was allowed to cool off at night, with the humidity rising to 100% and moisture condensing on the

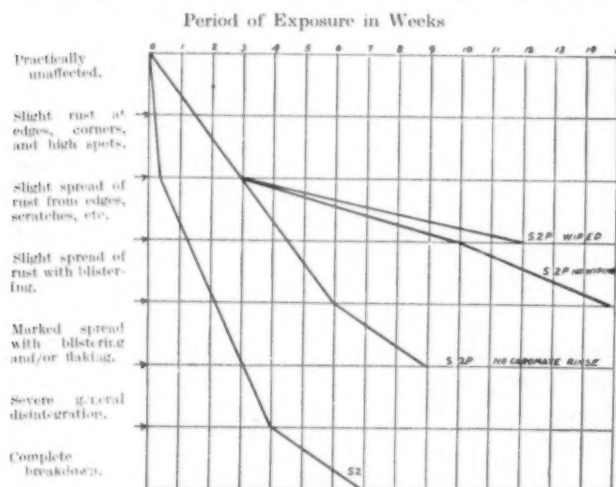


Fig. 4.—Results of salt-spray exposure on sheet mild steel specimens, showing the influence of chromate rinse and wiping prior to enamelling.

specimens. Under these not unduly severe conditions all the phosphatised specimens were entirely unaffected after six months. On the other hand, of those without phosphatisation, all lost adhesion which became very poor indeed in six months, and the one-coat samples became fairly generally rusted in this time.

In the foregoing, an endeavour has been made to deal with the problem of phosphatisation as a pre-treatment for steel work, broadly yet concisely. In conclusion, there is no need to restate the merits of the process, as these have already been clearly set out and stressed, but, before concluding, a few remaining features of note are worthy of inclusion. Solder, tin, brass, bronze, nickel-silver and such like metals are not adversely affected by the solutions involved in the process. Again, these solutions do not seep from crevices, seams, overlaps, etc., to cause dangerous corrosion in the same way that is experienced with pickling, electroplating, colouring and other chemical finishing compositions. In consequence, arc, flame and spot-welded, bolted, riveted and soldered equipments can be treated as assemblies and so dealt with more economically and conveniently than can be achieved in the component stage.

At the present time the keynote of production embraces the criteria of economy, minimum labour, maximum speed, minimum raw material and maximum quality. Paints and enamels are precious raw materials by virtue of the ingredients contained. Any means of reducing the volume of them used initially and in refinishing cannot be ignored. At the same time, the preservation of iron and steel assumes increased importance. The phosphatising processes are therefore of immediate moment; they are not luxury operations or processes the value of which is in question—they are foolproof, technically developed and controlled processes with a function to perform, a role in which they succeed beyond dispute.

## Tin and Its Uses

THE current issue of *Tin and Its Uses*, the quarterly review of the Tin Research Institute, examines the various trends in tin consumption in the United States in the present emergency. The relative merits of tin and the suggested alternatives are discussed, and it is concluded that major changes in the use of tin would involve substantial expenditure on research and new equipment, and are likely to be deferred so long as the supply position permits. American stocks and deliveries of tin are particularly favourable at present, and if the analogy of British experience is followed, war production will still further stimulate, rather than diminish, the consumption of tin.

Other articles in this issue include a description of an Australian test of the Institute's process for protecting tinplate against sulphur-staining by foodstuffs; a review of the use of tin in printing metals; an account of further improvements in tin foil; and a pictorial record of special uses of canned foods in war-time England.

Copies are obtainable free of charge from the Tin Research Institute, Fraser Road, Greenford, Middlesex, or in the United States from the Battelle Memorial Institute, 505, King Avenue, Columbus, Ohio.

## Heat in Industry

HEAT has always played an important part in industry, but it is only during comparatively recent years that its importance has been fully appreciated; it is now generally recognised, for instance, that the initial heating of steel exerts a considerable influence upon subsequent heat-treating and machining operations and upon the results obtained with the finished product in service. In any form of heat-treatment, the first consideration is to heat correctly, and in recent years old theories and practices have been largely discarded, to be replaced by newer, progressive methods of heat-treatment, which accelerates rather than retards the progress of industrial production.

Despite remarkable progress in the design and construction of heat-treatment equipment, selection is usually a matter of compromise between the ideal and the practical in reconciling requirements of quality with conditions related to methods of heating, cooling, and handling, variations in size or quantity of product, plant conditions, and other factors affecting the cost of installation and operation. No two cases are alike, and the services of furnace engineers should be sought, engineers who are not only builders of furnaces, but capable of designing furnaces to meet specific requirements.

One of the firms which has contributed considerably to the progress achieved in the development of new processes or the improvement of existing processes is British Furnaces, Ltd.: some excellent examples of their many contributions to the heat-treatment of both ferrous and non-ferrous metals are given in a booklet recently published. This booklet is both interesting and informative, and is excellently illustrated. Copies may be obtained on application to British Furnaces, Ltd., Derby Road, Chesterfield.

# Protective Painting of Structural Steel

*Facts concerning the best methods of protecting structural iron and steel work by means of paint are given in a paper by the Protective Coatings Sub-Committee, which is presented here in an abridged form. The choice of paint and painting procedures are discussed, but more emphasis is laid on the effect of the surface condition and pre-treatment before painting, which are the most important factors determining success.*

**T**HE problems arising from the corrosion of iron and steel are very serious and of great economic importance. Although authorities differ in their estimates of the wastage of iron and steel from this cause, the amount is recognised to be very high. Corrosion causes a large tonnage of iron and steel to go out of use each year, and while much is recoverable as scrap, the effects of oxidation results in much of it being a complete loss; it is not surprising, therefore, that methods are continuously being studied with the object of reducing wastage from this cause. This is especially true of structural iron and steel work and engineers and others are familiar with the maintenance difficulties arising from the rusting of these materials, necessitating some method of protecting the steel work from corrosion.

The Corrosion Committee of the Iron and Steel Institute has been investigating these problems since 1928. Its efforts have been directed both towards devising steels that are intrinsically more resistant to corrosion in the unprotected condition and towards improving the methods of protecting iron and steel against corrosive attack. Investigations of the latter aspect of the Committee's work has been intensified under the direction of the Protective Coatings Sub-Committee formed in 1936. These Committees have conducted a number of extensive investigations into the problem of protecting steel. Some of the results obtained have already been published; it is felt, however, that in view of the vast increase in the output of steel under war conditions, it would not be in the national interest to defer publication of their essential findings concerning the protective painting of structural steel work, which may be of particular assistance to those who have had no previous experience of this type of production. The Protective Coatings Sub-Committee has, therefore, compiled a statement,\* in which the practical conclusions deduced from their work in this field are set out in a concise manner. These conclusions are made with particular reference to a recent series of experiments which have been in progress for rather more than three years.

## Surface Preparation of New Steelwork

**Importance of Correct Surface Preparation.**—The correct surface preparation of steelwork prior to painting is by far the most important factor in determining the success of the protective coating. For example, in one series of tests the life of two-coat paint systems on a correctly prepared surface ranged from 6·8 to 9·0 years, whereas the life of the same systems applied to an incorrectly prepared surface varied from 0·6 to 3·7 years. It follows that, whatever steps may be found necessary to speed up production, it is not good practice to skimp the time devoted to surface preparation, since any time or labour saved thereby will be more than wasted later by the necessity for premature renewal of the protective coating.

**Value of Descaling.**—Practically all iron and steel used for structural purposes leaves the steelworks with a layer of mill scale on its surface. The presence of this scale under a protective paint film is generally detrimental to the behaviour of the latter. The best procedure, therefore, includes the removal of the mill scale either by pickling or by mechanical means before applying the paint.

**Comparison of Various Descaling Methods.**—There are three methods for removing mill scale from iron and steel:—

1. Pickling—that is, immersion in acid solutions which remove the scale without attacking the metal to any considerable extent; attack on the metal can be reduced to a minimum by adding certain chemical restrainers to the acid bath. Solutions of sulphuric hydrochloric and, less commonly, phosphoric acid, are used for the purpose.
2. Sand- and shot-blasting and other mechanical means, such as grinding and machining.
3. Weathering until the steelwork is sufficiently rusted to render the mill scale loose.

In the tests carried out particular attention was paid to comparing the effects of these different methods of descaling on the behaviour of paints applied to iron and steel. Over 400 painted panels were exposed, and there were representative of all commonly used methods of surface preparation, while four different irons or steels and two painting systems were adopted.

**Pickling.**—Wide variations occur in the conditions of operation of commercial pickling baths as regards the acid, used, the temperature and the acid concentration. Consequently, panels prepared by different pickling procedures were tested; the details of the most important of these are given in Table I.

Results of the tests to date have revealed practically no differences in the behaviour of paint on surfaces descaled by any of the fresh pickling baths when painting took place

TABLE I.  
PICKLING PROCEDURES TESTED.<sup>1</sup>

Hydrochloric Acid.	Sulphuric Acid.	Phosphoric Acid.
(1) 2% at 15° C.	(4) 5% at 80° C. <sup>2</sup>	(7) 12% at 80° C.
(2) 10% at 40° C. <sup>2</sup>	(5) (a) 5% at 80° C., followed by—	(8) 3% with 8% of dissolved iron at 80° C. <sup>3</sup>
(3) 1% with 8% of dissolved iron at 40° C. <sup>3</sup>	(b) 2% phosphoric acid with 5% of dissolved iron at 80° C. <sup>4</sup>	
	(6) 1% with 12% of dissolved iron at 80° C. <sup>3</sup>	

<sup>1</sup> The percentages are by weight.

<sup>2</sup> Both with and without a chemical restrainer.

<sup>3</sup> To represent a spent bath.

<sup>4</sup> The duplex process.

immediately after pickling; further, this behaviour was not affected by the presence of chemical restrainers or inhibitors in the baths. The spent baths, Nos. 3, 6 and 8, gave satisfactory results, but these were slightly inferior to those obtained from fresh baths. Consequently, it may be concluded that, provided that the pickling is properly conducted, the type of acid used and the operating conditions do not, within fairly wide limits, have a marked effect on the results. The main essential is that the strength of the bath be maintained at a sufficiently high concentration to ensure the complete removal of the scale. It is obvious that all free acid and soluble iron salts must be removed from pickled surfaces prior to painting them. This may be done with hot water, but hosing down with cold water is equally efficacious. In some plants the steelwork is immersed in hot lime-water to neutralise the last traces of acid. This procedure has been compared in the present tests with washing in hot water alone; so far the results show that either method gives satisfactory results when carefully carried out, but there is evidence that the use of lime-water allows a greater degree of latitude and does not require so much care.

\* Paper No. 5/1941 of the Corrosion Committee (Submitted by the Protective Coatings Sub-Committee to the Iron and Steel Institute.) Advance copy.

*Sand- or Shot-blasting.*—In the tests, mechanical methods of descaling, such as shot-blasting, proved as effective as pickling in securing a satisfactory surface for paint application. A reservation must be made that in this case it is essential to ensure that all rust is removed from the surface.

*Weathering.*—The results of the tests confirm emphatically the conclusions drawn from the work of the main Committee and of other investigators, that the third method of removing scale—i.e., by weathering until the mill scale lifts or flakes off, following by chipping, scraping and wire-brushing—is most unreliable and, with one exception, the worst method of preparing iron and steel surfaces for painting. In practice, it is impossible to remove the mill scale completely from a large structure by this method, and even with the utmost care much mill scale is left.

From time to time suggestions are made that weathering should be artificially stimulated by moistening the surface at intervals with various solutions, and this procedure was tried. Specimens were wetted at intervals with a solution of calcium chloride during their exposure in the open, and they were finally wire-brushed before painting. This treatment gave the worst results of all, probably because traces of the salt were locked up in the rust remaining in the pores of the surface after wire-brushing.

*Effect of Interval Between Descaling and Painting.*—The tendency of any freshly descaled iron or steel surface is to rust immediately; this tendency is particularly pronounced in the humid and polluted conditions that are common in Great Britain. It is logical to conclude, therefore, that the interval elapsing between the removal of the mill scale and painting should be as short as possible, and the experimental results have demonstrated that this is the case. It was found that the best results were obtained when the application of the priming coat was carried out immediately after the pickling and washing process, although storage indoors for periods of up to 30 days did not cause any serious loss of durability; in the latter case much will obviously depend on the condition of storage. If a good corrosion-inhibiting priming paint is used, satisfactory results can be obtained after short periods of exposure to the weather after pickling, provided that steps, such as scraping and wire-brushing, are taken to remove the loosely adherent rust formed, but such practice should be avoided wherever possible.

The practical conclusion is that the priming coat of paint should be applied immediately after the descaling operation. Good pickling procedure would consist of rinsing the steel removed from the pickling bath in hot water, allowing it to dry thoroughly as a result of its own heat capacity, and painting it while it was still warm. This procedure should be practicable in many cases; for instance, at one works, plates for tank-holders are fabricated, bent and drilled before pickling, treated in the way described and despatched to the site in a primed condition.

It may be added that there is some evidence that the use of the duplex pickling process (Table I, No. 5 may allow of an increased margin between pickling and painting, owing to the retarding effect of the final immersion in phosphoric acid on the development of rusting.

*Surface Washes.*—A number of proprietary washes are on the market which, it is claimed, have the power of preventing rusting underneath paint coats, or of neutralising the bad effects of existing rust on a structure that is to be repainted. These washes generally contain phosphoric acid and/or compounds of chromium; one such proprietary wash was included in the tests. It was found to be of doubtful benefit when used on rusted surfaces; indeed, in certain cases, its use led to decreases in the durability of the painting schemes. In other tests, in which inhibitive washes were applied to rust-free surfaces still covered with mill scale, it was found that they led to premature flaking and failure of the paint film; failure occurred on the undersides, which, not being directly exposed to sunlight, often remained wet as a result of condensation.

Therefore, it is the considered view of the Sub-Committee that these compounds cannot be relied on to prevent bad results from painting over mill scale and/or rust; the only safe procedure is to remove the scale and rust by pickling or mechanical means. In any case, it is bad practice to allow steel to rust before painting it.

*Alternative Procedures when Descaling Cannot be Adopted.*—As a general principle, it is false economy to adopt the attitude that descaling is impracticable or that there is not time for the process, although it is true that the steel-maker or the fabricator may be put to additional trouble or the completion of the work may be slightly delayed by the adoption of descaling. Any increase in expenditure of time or materials is more than offset by the fact that the user of the finished product avoids considerable trouble resulting from the premature failure of the protective coating and possible damage to the structure from corrosion.

On the other hand, if for any reason descaling is definitely impracticable, the common procedure of exposing steelwork to the weather until the mill scale is removed, as a result of rusting, may be used, provided that those responsible are reconciled to a greatly reduced life of the initial painting and are prepared to renew the painting after, say, one year's exposure. Another alternative, where pickling or shot-blasting is impracticable, consists in endeavouring to maintain intact mill scale on the steel before painting. This can be done to some extent by taking steps to avoid undue exposure of the steel to the weather and by applying a thin protective coating to the surface at the first available opportunity. Of the available materials none functions so well as red-lead paint.

It must be realised that surfaces that are completely covered with intact mill scale cannot be obtained with certainty over large areas under practical conditions, since the mill scale rarely forms a complete covering of the bare metal. There is, too, a tendency for the mill scale to rise in places beneath the paint film, and cause blisters or failures. Hence, although good results may sometimes be obtained by painting over mill scale, the general adoption of this procedure is not recommended.

#### Choice of Paints for New Steelwork

*False Economy of Cheap Paints.*—An analysis of the costs of protective painting will show that the cost of the paint forms only a small proportion of the total costs, especially in the case of the painting of completed structures, where the costs of cleaning and scaffolding are often paramount. The choice of paints, therefore, should not be made solely on a price basis, quality or protective power being the first criterion. In this connection other investigators have shown that the addition of unlimited amounts of extenders (that is, of pigments chosen for the purpose of cheapening the paint) to red-lead paint has a deleterious effect upon the protective value of the paint when the quantity added exceeds a maximum percentage. Certain pigments, however, are sometimes added for technical reasons—for instance, to prevent settling or to ease application—and, provided that care is used in the choice of the additional pigment, it is often sound practice to do this. Indeed, although what has been said concerning the uncontrolled admixture of extenders with red-lead paint can be generally applied, often a paint containing mixed pigments is superior to one containing any one of them singly.

*Value of Corrosion Inhibiting Primers.*—The best results are obtained when the paint applied directly to iron and steel is pigmented with materials that repress the tendency of the steel surface to corrode; paints of this type are known as "inhibitive" paints. For example, in the tests discussed in this report it has been found that specimens painted with one coat of red-lead primer and one coat of red oxide of iron finishing paint have been more efficiently protected than similar specimens painted with one coat of red iron oxide primer, and one coat of white lead + zinc oxide finishing paint.

The following pigments are known to have inhibitive properties: Red lead, white lead, lead chromate, blue lead (basic sulphate of lead), zinc chromate and other sparingly soluble chromates, zinc dust and possibly zinc oxide. The Committee's tests have shown that the most effective of these primers for general use is red lead and that chromate pigments are not on the whole quite so good; they give good protection in rural and marine atmospheres, but are inferior to red lead in industrial atmospheres. The relative efficiency of the remaining pigments has not been established with certainty.

A few suitable formulations are given in Table II. The numbers of the normal and the war emergency British Standard Specifications relating to the pigments and other ingredients will be found in Table III.

There is no point in priming galvanised sheets with red-lead paint unless they have been damaged or so badly corroded as to expose the steel base, since the zinc coating itself inhibits the corrosion of steel. Prepared tars and bituminous paints often give good results on properly prepared galvanised sheets, but if an oil paint is required red oxide of iron can be used.

TABLE II.  
COMPOSITIONS OF CORROSION-INHIBITING PRIMING PAINTS FOR IRON AND STEEL.

	Red Lead.	White Lead.	White Lead and Zinc Oxide.	Lead Chromate.	"Blue Lead."	Red Oxide and Zinc Chromate.
Pigment .....	80	77	78 <sup>1</sup>	66	90 <sup>2</sup>	69 <sup>3</sup>
Raw linseed oil .....	—	—	—	—	5	—
Refined linseed oil .....	11	6	9	16	—	13
Boiled linseed oil .....	4	12	9	16	4	13
Turpentine .....	1	4	—	—	—	—
White spirit .....	—	—	3	—	—	2
Driers .....	1	1	1	2	1	3

<sup>1</sup> White lead 52%, zinc oxide 26%.

<sup>2</sup> This pigment is obtained by the controlled oxidation of galena; approximately one-half consists of lead sulphate, one-third of lead monoxide, and the remainder of lead sulphide, zinc oxide, etc.

<sup>3</sup> Red oxide of iron 53%, zinc chromate 16%.

**Finishing Paints.**—The best general finishing paints available in quantity for use over red lead are red oxide of iron, white lead or micaceous iron ore. During the war emergency particularly, alternatives to the linseed-oil paints should be considered; chief among these will be tar paints. The merits of tar, especially in coastal and marine conditions, has already been established, and the extended use of tar should be considered as a means of reducing imports, while at the same time maintaining the protection of structures undiminished. Red lead and tar used in combination provide excellent protection; one coat of red lead followed, after an interval of not less than one month, by one coat of tar which has been neutralised with lime and treated with tallow is a scheme which has been used with much success.

### Painting Procedure

**Importance of Good Painting Conditions.**—In order to obtain the best results, all painting should be carried out under dry conditions when the air is reasonably warm—say, 60° F. or more—and the humidity is not unduly high—say below 90%. If possible, the operation should be conducted under cover; this cannot be done when repainting existing structures in the open, but, with few exceptions, there is no reason why the initial priming coat of structural steelwork should not be applied under cover.

It is obvious that difficulties must arise in applying these considerations in practice and that it may sometimes be impossible to adhere to them closely, particularly under war conditions. Nevertheless, in many cases, by giving a little thought to the matter, much can be done to ensure that the painting of steelwork takes place under favourable circumstances. Any little extra trouble taken in this way will be more than repaid by the better results obtained.

**Spray versus Brush Application.**—It is difficult to give a final answer to the question whether spray-painting or brush-painting gives the better results. The fact is that a

strict comparison of the two methods of painting is no always possible. As regards speed, in the majority of cases the advantages undoubtedly lie with spraying; on the other hand, it has to be appreciated that certain types of lead paints are only suitable for brush application. As against this, other types of materials, such as cellulose finishes, are best suited to spray application. It is possible, within the types of paint normally employed in the painting of structures, to obtain a more uniform coating by spray application than by brush, and there is abundant evidence to show that brush marks in films applied by brush constitute sources of relative weakness in the film as a whole.

TABLE III.  
BRITISH STANDARD SPECIFICATIONS FOR PAINT MATERIALS LISTED IN TABLE II.

Material.	Normal.	War Emergency.	
	R.S.S. No.	Date.	R.S.S. No. Date
Red lead .....	217	1936	
White lead .....	239	1935	
Zinc oxide .....	254	1935	
Lead chromate .....	282	1938	927 1940
	272 Natural	1936	
	305 Manufactured	1936	
	694 Blended	1936	
Zinc chromate .....	389	1938	
Linseed oil: Raw .....	243	1936	
Refined .....	242	1936	925 1940
Boiled linseed oil .....	259	1936	
Turpentine: Type 1 .....	244	1936	
Type 2 .....	290	1936	925 1940
White spirit .....	245	1936	
Driers: Liquid .....	332	1938	925 1940
Paste .....	331	1938	

### Repainting of Old Steelwork

**Excessive Deterioration of Old Paint to be Avoided.**—The guiding principle for ensuring success in protection by painting is that no rust should be allowed to form beneath the original coat of paint; the same principle holds good so far as repainting is concerned. In other words, an existing paint film on structural steel should never be allowed to deteriorate to such an extent that rusting occurs beneath it, for if this happens extensive cleaning down and scraping to the bare metal will be necessary. Moreover, since it is impracticable to pickle an erected structure, a clean metallic surface will be unobtainable (unless, of course, shot-blasting is resorted to, which is costly and not always practicable). This means that the coating applied on repainting will have a shortened life; in fact, the evil may not be completely eradicated until the structure has been repainted several times.

As soon, therefore, as the paint film itself begins to show signs of failure, whether by chalking, cracking, blistering or under-rusting, an additional coat of paint should be applied over it. If failure is adjudged to have occurred as a result of blistering or under-rusting, the latter of which will be revealed by rust stains, care should be taken to make sure that the old paint film is perfectly sound and adherent; if not, it should be removed. It must also be borne in mind that the development of chalking is a natural process in the weathering of certain paints, and does not necessarily mean that they have lost their protective value to the extent of justifying repainting. If corrosion has occurred in isolated places, the surface should be cleaned down as thoroughly as possible and primed with an inhibitive primer; these areas might with advantage receive an additional coat of finishing paint. Paint in a sound condition should not be unnecessarily removed.

**Surface Preparation and Cleaning Tools.**—If, as should be the case, the old paint film is firm and adherent, no elaborate surface preparation is necessary; in the optimum case, a simple washing-down with bristle brushes and clean water should suffice. The paint should naturally be allowed to dry thoroughly before the new paint is applied. If the paint film is sound but contaminated with oil or grease, it should be wiped with a rag dipped in white spirit to remove them.

If deterioration of the old paint film has been allowed to take place and actual rusting has occurred, it may be necessary to remove the old paint as well as the rust. A

flame-descaling process may be useful in this connection; in essentials this consists in burning off the paint with a wide, multi-jet oxy-acetylene burner, which is passed over the surface of the structure. The steel is heated and is painted while it is still warm.

Failing these methods, resort must be had to hand-cleaning by means of hammers, scrapers and wire brushes, which is an expensive process when effectively carried out. The process can be facilitated by mechanical tools.

#### Special Cases

*Paints for Anti-glare Structures.*—Considerable trouble is experienced from the corrosion of structural steelwork and steel sheets used for the structures erected over blast-

furnaces, coke-ovens, and the like, in order to prevent the emission of glare from these plants during black-out hours. This results from the fact that the steel is subjected to high concentrations of corrosive gases and steam at temperatures well above the normal. The combination of corrosive gases and elevated temperature is such as to cause breakdown of many of the most usual protective coatings and premature failure of the sheets.

The Committee has been investigating the problem and has made progress in the choice of suitable protective coatings for the purpose, and the information obtained will be made available to any *bona-fide* engineer or works manager experiencing trouble from this cause. Inquiries should be addressed to the Secretary of the Iron and Steel Institute.

## Investigation of the Influence of Mould Friction on Tearing in Castings

THE disastrous effect of the hot tearing of steel castings of complicated design is well known and is generally attributed, among other things, to the resistance offered by the sand to the contraction of the casting, with the result that many methods are employed to ease the casting and permit it to contract with as little resistance as the design of the casting warrants, such as releasing the sand surrounding projections, the use of collapsible cores, etc. Immediately after solidification the steel is very weak, yet considerable contraction takes place at this time, and although a mould should be weak enough to permit the casting to contract without rupture, it must be strong enough to resist the rush and pressure of the molten metal at the time of casting. Methods for weakening the mould or cores after casting constitute so far the only means by which rupture is minimised, and very often prevented altogether. But it will be appreciated that, with some castings, these sample preventives, although applied, cannot be expected to be fully effective, and the steel founder has then to rely on the skill of the welder to make his castings acceptable.

During contraction the casting must obviously move, however slightly, and in the case of complicated box-like castings this contractional movement is uniform in neither rate nor direction. The former depends upon the uniformity of temperature, and the latter on the design of the casting, the location of cores, etc. The actual position of the resulting "tear" is that portion of the casting which, at the moment when these contractional stresses and sand resistances cannot be resisted further, is the weakest—namely, the hottest position. Coupled with this resistance offered to the contracting casting by the body of the sand itself is the possibility that there is actual friction between the sand grains and the surface of the casting. If this mould friction is great, then the normal movement of the casting is further restricted and the liability to tearing is augmented.

In order to determine whether mould friction is a contributory cause to the tearing of steel castings, a series of experiments have been devised and carried out; these are described by Professor J. H. Andrew and H. T. Protheroe.\* Long steel bars were cast in various grades of sand in a series of moulding boxes, which enabled different volumes of each grade of sand to be employed.

From the large number of tests carried out it would appear that hot-tearing is due rather to the resistance offered to contraction by the bulk of sand than to the nature of the sand itself. When steel castings are stripped from the moulding box there is a thin layer of burnt sand between the face of the casting and the main body of the sand. This layer is very friable, and if the refractoriness was originally sufficient it is easily removable from the casting; it is not likely, therefore, that any resistance is offered to the contractional movement of the casting from this cause. It is possible, however, that friction between molten metal

and the sand will increase with increase in coarseness of the sand.

Examination of the test castings showed sulphur segregation near the runner and riser, but no attempt is made to explain this segregation. The authors consider that the temperature at the crucial moment during contraction will decide where the casting tears. In every test carried out this was near the runner—that is, in the hottest region, but if uniformity of temperature were possible, the bar is likely to crack elsewhere and would then be influenced by impurities in the metal.

With regard to casting temperature, the only deduction possible from the varied number of casting temperatures employed is that tearing occurs some time after solidification, probably very soon afterwards, because it is known that at such temperatures steel is very weak, and it is also known that steel contracts at a quicker rate at high than low temperatures. These facts indicate that tearing occurs near the solidification temperature. Experiments showed that provided the runner is sloped away from the end of the casting, hot tearing will not occur.

It should be pointed out that these tests were concerned with steel castings made in green sand, and they were straight and of uniform section, with a runner and riser at opposite ends. Practically only relatively small steel castings are made in green sand, and the majority of castings vary in sectional thickness, besides being more complex in design. Castings made in green sand, unless they are very small and light in section, are liable to carry patches of fused sand which do not strip from the castings easily, and these will obviously offer resistance to the contractional movement of the metals.

For medium- and larger-sized steel castings the moulds are invariably dried and given a special wash of some refractory material which reduces the possibility of fusion of the sand and metal and permits the molten metal to flow more easily; on the other hand, however, such a mould is stronger and, when the shape is complicated, it offers greater resistance to contraction. In fact, it is found in practice that castings of different design cast from the same ladle of metal do not contract the same amount when checked by measurement; which mould receives the metal from the ladle first does not perceptively affect this result. It is probable that the design of the casting coupled with the strength of the mould are the factors which influence most the free movement of steel when cooling which may cause a tear or rupture. Although rupture may not take place in a complicated casting, many must be handled with great care when they are removed from their mould because of contraction stresses, and until they have been subjected to a stress-relieving treatment they are liable to crack or actually break without warning.

The contraction problems associated with the production of steel castings are considerable, and of the factors that influence tearing from this cause that of mould friction can be regarded as of minor importance.

\*Paper No. 2/1941 of the Steel Castings Research Committee. The Iron and Steel Institute. (Advance copy.)

# The Influence of the Vanadium Content upon the Properties of Low-alloyed High-speed Tool Steels

By D. W. Rudorff, A.Am.I.E.E., M.Inst.F.

*Low-alloyed high-speed steels of the tungsten-molybdenum-chromium type, containing vanadium, have been systematically studied in order to determine the influence exerted by the latter element. The work done is summarised in this article, and particular attention is directed to the results obtained.*

THE influence of the vanadium content upon the properties of low-alloyed high-speed tool steels of the W-Mo-Cr type is the subject of a recent systematical study made by A. P. Gulyaev. The following steels were prepared in a high-frequency induction furnace and cast into ingots of 8-10 kilograms in weight.

Steel Type.	C.	V.	W.	Mo.	Cr.
0.8 C	0.769	—	3.2	3.1	4.1
0.9 C, 2.3 V	0.94	2.3	3.1	3.0	4.1
1.1 C, 3.0 V	1.17	3.0	3.2	2.9	3.9
1.4 C, 3.0 V	1.41	3.2	3.1	3.5	4.3
1.3 C, 5.0 V	1.36	5.5	3.3	3.1	4.4
1.5 C, 6.7 V	1.45	6.7	3.3	3.3	4.0

No data are contained in the original report\* with regard to the amounts of manganese, silicon, nickel, sulphur and phosphorus contained in the various samples, but it is understood that these did not exceed the usual percentages permissible for high-speed tool steels. The ingots were reheated to 880° C., and then forged into bars of 15 × 15 and 8 × 8 mm. section. All samples were found to have excellent forging properties, irrespective of the vanadium content. The forged pieces were annealed at 880° C., with a cooling rate of 40° C. per hour.

## The Austenitic Transformation

**Isothermal Transformation in the Upper Range.**—The decomposition of the austenite was studied by establishing the various S curves, which render the time of initiation of the isothermal decomposition of the austenite at various temperatures. The initial heating temperature varied from 1,220° to 1,280° C. From Fig. 1 it is seen that the vanadium content acts to raise the "nose" of the S curve with regard to temperature, and to shift it in the direction of decreasing time of reaction.

**Isothermal Transformation in the Middle Range.**—In Fig. 2 are shown the magnometric curves characterising the isothermal transformation of the austenite in the second critical range at 300° C. These curves show that in all

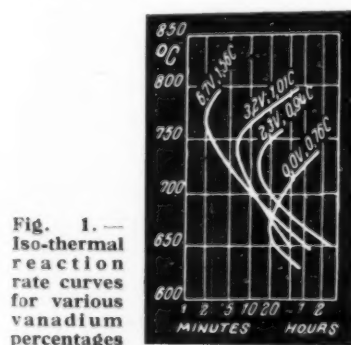


Fig. 1.—Iso-thermal reaction rate curves for various vanadium percentages

test pieces containing vanadium, the transformation terminated within 3 hours. Cooling to room temperature did not cause martensitic transformation of the residual austenite which remained in considerable quantity. In the

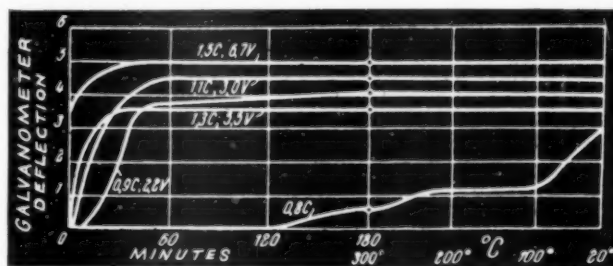


Fig. 2.—Iso-thermal decomposition of austenite at 300° C.

steel containing no vanadium, isothermal decomposition of the austenite began only after 2 hours' treatment, and took place in a sluggish manner; martensitic transformation began at 100° C.

**Martensitic Transformation.**—The location of the martensitic point of the various steels for varying temperatures of hardening (ranging from 1,100° to 1,250° C.) is given in the table shown hereunder, the data having been obtained with the magnometric method.

Steel Type.	Quenching Temperature, ° C.		
	1,100	1,200	1,250
0.8 C	260° C.	170° C.	120° C.
0.9 C, 2.3 V	390° C.	250° C.	200° C.
1.1 C, 3.0 V	380° C.	280° C.	230° C.
1.3 C, 5.0 V	400° C.	300° C.	270° C.
1.5 C, 6.7 V	—	410° C.	360° C.

This table evidences that in all steels investigated, increased hardening temperature leads to a lowering of the martensitic point, while increased vanadium content tends to raise this point. The amount of residual austenite in the various steels, after quenching from various temperatures, is shown in the diagrams reproduced in Fig. 3. Here it is seen that the amount of residual austenite prevailing increases with the temperature of hardening. Referring to Fig. 4, it is evident that for constant hardening temperature, the quantity of residual austenite decreases with

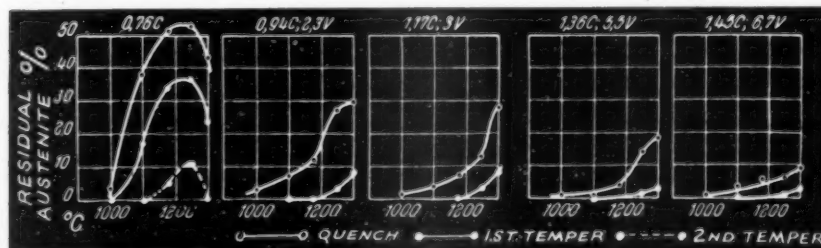


Fig. 3.—Influence of quenching temperature upon the amount of residual austenite.

increasing vanadium content. A first addition of vanadium (up to 2%) decreases the residual austenite content to a greater degree than subsequent additions.

Referring to Fig. 5, it is seen that a straight-line relationship exists between the amount of residual austenite

\* *Steel*, No. 4, 1941, p. 55, et seq.

and the martensitic point. But it is also seen that the angle of incidence of the straight lines decreases with increasing vanadium content. For a given martensitic point, the amount of residual austenite therefore is greater the smaller the vanadium content. Thus, for instance, for a martensitic point of  $200^{\circ}\text{C}$ ., the respective degrees of transformation are:—

For 0.8 C steel .....	55% martensite.
.. 0.9 C, 2.3 V steel ..	75% ..
.. 1.1 C, 3.0 V steel ..	80% ..
.. 1.3 C, 5.5 V steel ..	91% ..

Vanadium is seen not only to raise the martensitic point contributing to a higher degree of transformation of the austenite into martensite, but also to increase the transformation at identically lowered martensitic points.

### The Influence of the Temperature of Hardening upon the Microstructure and Hardness of the Steel

The original report points out that a study of the microstructure of the samples quenched from various temperatures showed that, while with increasing hardening temperature the carbides dissolve and the austenitic grain grows, the growth of the austenitic grain is progressively retarded by increasing vanadium content. Likewise, at constant temperature of quench ( $1,220^{\circ}\text{C}$ .), it was found that the austenite grain decreases in size with increased vanadium content. In a steel with 2.3% vanadium content, no austenite grains could be observed at  $1,150^{\circ}\text{C}$ .

Vanadium also increases the temperature at which Ledeburite originates. Thus, in the steel free of vanadium the Ledeburite appears with a hardening temperature of  $1,200^{\circ}$  to  $1,240^{\circ}\text{C}$ ., while in the steel containing 2.3% vanadium it appears with a temperature of quench between  $1,260^{\circ}$  to  $170^{\circ}\text{C}$ ., and in the steel containing 5.6% vanadium it appears with a temperature range from  $1,300^{\circ}$  to  $1,320^{\circ}\text{C}$ .

The relationship between hardness and temperature of quench, as it was observed with the various steels, is charted in the diagram, Fig. 6. In the case of the vanadium free steel, maximum primary hardness is registered with a hardening temperature of  $1,000^{\circ}\text{C}$ . With increasing temperature the hardness of this steel is seen to decrease. This is obviously due to the increase in the amount of residual austenite. Overheating at  $1,200^{\circ}$  to  $1,220^{\circ}\text{C}$  is seen to be accompanied by an increase in hardness. In the case of the steels containing vanadium, the attainment of maximum primary hardness requires increasingly high

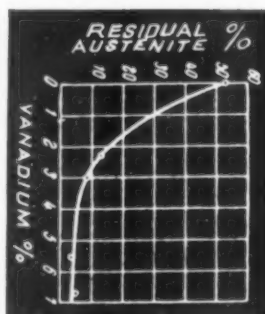


Fig. 4—Residual austenite content after quenching from  $1,180^{\circ}\text{C}$ . as influenced by vanadium content.

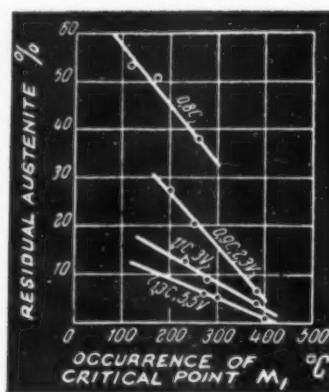


Fig. 5.—Inter-relationship between occurrence of critical point M, and quantity of residual austenite (hardened steel)

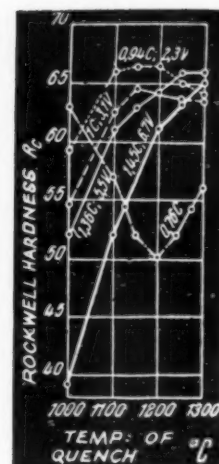


Fig. 6.—Hardness versus hardening temperature.

temperatures as the vanadium content is increased.<sup>1</sup> As Fig. 6 shows, maximum primary hardness in the steel containing 6.7% vanadium is not reached within the temperature range considered.

The influence of the vanadium content upon the properties of the steel with change in the temperature of quench is due to the resistance to decomposition of the vanadium carbides. Steels with a higher vanadium content exhibit for a given temperature of quench a smaller grain size, since the abundant carbides impede grain growth.

Furthermore, the resistance of vanadium carbides<sup>2</sup> to decomposition makes the steel less sensitive to fluctuations in the hardening temperature, as a moderate deviation in temperature affects little the amount of carbide entering into solution. With low hardening temperatures of about  $1,000^{\circ}\text{C}$ ., the steels exhibit decreasing hardness with increasing vanadium content, as progressively increasing amounts of carbon remain undissolved as vanadium carbides. Vice versa, with higher hardening temperatures at which a considerable portion of vanadium carbides have entered into solution, the primary hardness is seen to increase with the vanadium content, because vanadium decreases the amount of residual austenite.

### The Influence of the Temperature of Draw : Martensitic Transformation

In order to study the influence of the tempering temperature upon the change in hardness, the investigated test pieces, hardened from various temperatures, were, sub-

Fig. 7.—Influence of tempering temperature upon hardness for different temperatures of quench.

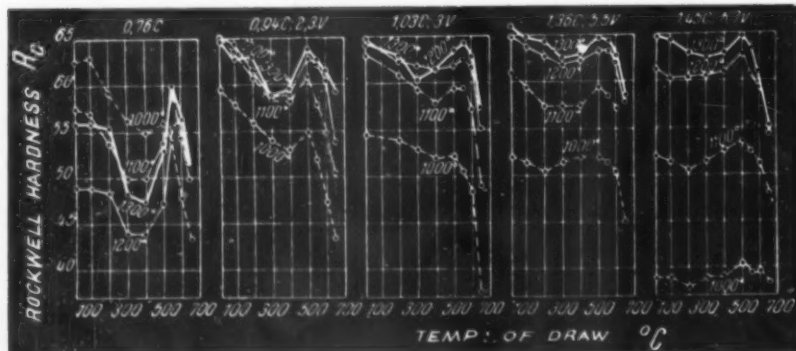
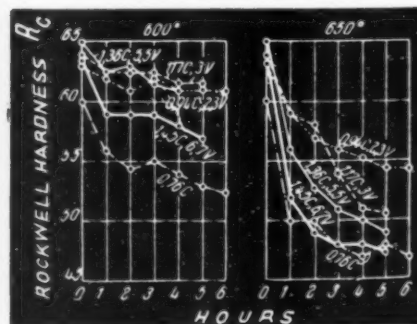


Fig. 8.—Red-hardness as influenced by heating time.



<sup>1</sup> "Vanadium carbide is dissolved in  $\gamma$  iron less readily than iron carbide, and steel in which some of the carbon is combined with vanadium does not attain its full hardness when quenched from the usual temperature. If, however, the hardening temperature is raised and more of the vanadium carbide dissolved, higher hardness is obtained in quenching." H. H. Abram, "Influence of V on Ni-C<sub>2</sub> and S-C<sub>2</sub>-Mo steels," Iron and Steel Institute, vol. 134, 1936, p. 241.

<sup>2</sup> Regarding the nature of vanadium carbides, see E. Maurer, T. Doering, and W. Pulewka, *Archiv. Eisen. Huettenwesen*, vol. 13, Feb., 1940, p. 337/44, who found in an analysis of seven different steels the presence of two vanadium carbides with compositions V<sub>4</sub>C and V<sub>5</sub>C<sub>3</sub>.

sequently, tempered at 100°, 200°, 300°, 400°, 500°, 550°, 600°, and 650° C. The results of this investigation are charted in the graphs reproduced in Fig. 7. Secondary hardening is seen to take place with tempering in the range from 500° to 600° C., while the hardness falls with tempering in the range of 300° to 400° C. This fall is attributed to the decreased amount of residual austenite under the influence of the vanadium content. The following conclusions were reached: (1) Increased temperature of draw or increased length of time of draw increases the temperature of secondary martensitic transformation and decreases the amount of residual austenite after the tempering; (2) with a given temperature, or with a given length of draw, the temperature of the secondary martensitic transformation increases with increasing vanadium content of the steel. The amount of residual austenite for a given range of tempering decreases with increasing vanadium content.

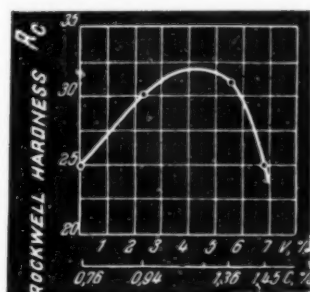


Fig. 9.—“Hot-hardness” versus vanadium content.

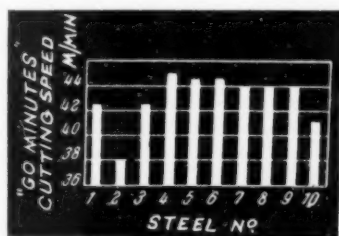


Fig. 10.—“60-minutes” cutting speeds of ten various steels investigated.

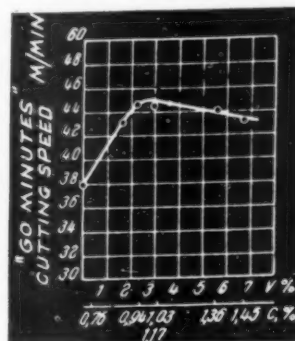


Fig. 11.—“60-minutes” cutting speed versus vanadium content.

### The Red-hardness

The red-hardness of the various test pieces was obtained by the following method, to wit:—

(1) Measuring the hardness after progressively increased temperatures of draw in the range of 500° to 600° C. (in steps of 20° C.).

(2) Measuring the hardness of the hardened and tempered test pieces after having been kept at 550°, 600°, 650° and 700° C. for various lengths of time.

(3) Dilatometric observation of the decomposition temperature of the martensite with heating.

(4) Measuring the “hot-hardness” at 700° C.

The data obtained with the employment of the first method showed that a change in the hardening temperature in the range of 1,240° to 1,300° C. has little influence upon the red-hardness of the steel after tempering at progressively increased temperatures of draw in the range of 500° to 600° C. Of the various steels, those with 2.3% and 3.0% vanadium showed the greatest stability of hardness; while the steels with greater and with smaller vanadium content exhibited a smaller degree of red-hardness.

The second method was carried out by first hardening the test pieces from 1,240°, 1,270° and 1,300° C. and tempering them at 560° C. After that their red-hardness was investigated by repeatedly keeping the pieces for 1 hour at one of the following temperatures—550°, 600°, 650° and 700° C., and subsequently measuring their hardness. The investigation showed that:—

(1) The pieces hardened from highest temperature showed stability of hardness. The advantage derived from hardening from highest temperature was particularly pronounced with high-heating temperatures.

(2) With the exception of the steels with 1.5% C and 6.7% V, the hardness remained stable for 5–10 hours with 550° C. temperature.

(3) All steels investigated lose their hardness rapidly at 700° C.

(4) The best red-hardness results were obtained at 600° to 650° C.

From Fig. 8 it is seen that at 600° C. (after hardening from 1,270° C.) the steels with 2.5%, 3.0% and 5.5% V showed best red-hardness; while remarkably high red-hardness at 650° C. was shown by the steel containing 2.3% V.

The temperature at which decomposition of martensite begins with heating was ascertained with a dilatometer. In the case of the steel containing 0.8% C, the martensite transforms at 650° C.; with the 0.9% C and 2.3% V steel this transformation also occurs at 650° C. With the steel containing 1.1% C and 3.0% V the transformation occurred at 680° C., with the steel containing 1.3% C and 5.5% V the temperature was 600° C, and with the steel with 1.5% C and 6.7% V the transformation temperature was found to lie at 560° C. It is thus seen that the 3% V steel possesses the greatest stability in this respect. As Fig. 9 shows, greatest “hot-hardness” at 700° C. is obtained with 4% V content.

### Cutting Properties

The cutting tests were made on a low-alloyed chrome-nickel steel of 200–180 Brinell, no cutting fluid being employed. The chip section was 3 × 0.31 mm. Additional

cutting tests were made with a 3.8–4.6 Cr, 17–18.5 W 0.5–0.8 V standard high-speed steel, as well as with two samples of a steel of the 1.0 C and 3.0 V type in which the vanadium content was reduced to 1.7%, but containing 1.5 W and 0.9 Mo, respectively. The cutting characteristics were evaluated by establishing the 1-hour tool life from the  $T = f(V)$  curve. The various test data are summarised in the graph shown in Fig. 10 and in the subjoined table:—

COMPOSITION, HARDENING TEMPERATURE, AND TEMPERING TEMPERATURE OF THE STEELS TESTED FOR CUTTING PROPERTIES.

Steel No.	Constituents, %					Quenching Temp., °C.	Tempering Temp., °C.	Number of Tempers.
	C.	Mo.	W.	V.	Cr.			
1	0.71	—	17.6	0.53	4.2	1,300	560	3
2	0.76	3.1	3.2	—	4.1	1,200	560	3
3	1.05	2.8	—	1.7	3.8	1,190	560	3
4	0.94	3.0	3.1	2.3	4.1	1,250	560	2
5	1.01	3.5	3.1	3.2	4.3	1,270	560	2
6	1.17	2.9	3.2	3.0	3.9	1,270	560	2
7	1.36	3.1	3.3	5.5	4.4	1,290	560	2
8	1.45	3.3	3.3	6.7	4.0	1,290	560	2
9	1.06	3.2	1.5	3.1	4.2	1,270	560	2
10	1.05	0.9	3.1	3.6	4.8	1,270	560	2

From these test results the following conclusions were drawn:—

(1) The influence of the vanadium content upon the 1-hour tool life corresponding to a cutting speed  $V_{60}$  (m./min.) (“60 mins. cutting speed”) is expressed by a curve with a maximum, this maximum representing the optimum vanadium content (see Fig. 11). In steels containing 3% W, 3% Mo, and 4% Cr, initial additions of vanadium cause a sharp improvement in cutting properties, but with vanadium additions in excess of 2–3% the tool life begins slowly to decrease. The optimum vanadium content can, therefore, be assumed to lie at 2.5%.

(2) Steels with optimum vanadium content give better cutting properties than steel (1).

(3) A decrease in vanadium from 2.3% to 1.7% (steel (3)) leads to diminished cutting properties, lowering the 60-mins. cutting speed by about 5%.

(4) In steels containing 3% V, 3% W, 3% Mo and 4% Cr, lowering the tungsten content to 1.5% does not diminish the cutting properties, but a lowering of the molybdenum content to 0.9% considerably lessens the cutting properties.

# Low-Alloy Steel Castings

*The composition and properties of low-alloy steel castings and their manufacture from available raw materials is discussed in the light of the strategic importance of most of the alloying elements used.*

FOR several years there has been in production a group of low-alloy steel castings somewhat analogous to the low-alloy, high-strength wrought steels. The latter have been widely discussed and are extensively used, but very little has been published regarding the former. A discussion, therefore, on their composition and properties, and their manufacture from available raw materials, is of value, particularly at the present time when the production of these steels is difficult, due to the strategic importance of most of the alloying elements used, and this has resulted from a paper presented by G. H. Lorig\* at a recent meeting of the American Foundrymen's Association.

The low-alloy steels in regular production for steel castings are the medium manganese (1 to 1.6% manganese), the low-nickel (2% nickel), the nickel-manganese (0.5 to 1.5% nickel, 1 to 1.6% manganese), the nickel-chromium (1.5% nickel, 0.75% chromium), the nickel-chromium-molybdenum (1.5% nickel, 0.5% chromium, 0.2% molybdenum), the nickel-molybdenum (1.5% nickel, 0.3% molybdenum), and the nickel-vanadium (1.25% nickel, 0.1% vanadium). For reasons of cost, medium manganese steels are often used in preference to low-nickel steels.

Steel containing 1 to 1.6% manganese, despite its ductility, tends to be low in impact resistance, and a sufficient manganese content for a very high yield strength, without the presence of corrective elements, accentuates the poor impact behaviour and introduces trouble from castings cracking in the mould. Hence, the tendency is towards keeping the manganese at from 1 to 1.2%, with additions of molybdenum or chromium to increase the yield strength, or to use with higher manganese either such additions as titanium or vanadium to produce a fine grain, as well as an improved yield, or to use chromium together with vanadium.

In terms of alloying behaviour, nickel goes into solution in ferrite and strengthens without loss of toughness, while manganese, chromium and molybdenum form carbides and tend to increase strength with some loss of toughness. In nickel-free steel the use of titanium or vanadium, or some similar grain refiner, is to restore toughness through small grain size. In seeking equivalent steels without nickel, and with as little manganese as possible so as to avoid the need for elements of present or potential scarcity, it is necessary to add ferrite-strengthening, non-carbide forming elements, such as copper and silicon, so as to come as nearly as possible to the effects supplied by nickel. For strengthening, small amounts of chromium might also be used when available, but molybdenum is generally regarded as more suitable. Another reason is that both copper and molybdenum are less oxidisable than iron, and can be added to a charge at any stage without loss and without effect on the slag or the steel-refining process. Supplies of ferro-carbon-titanium or ferro-vanadium are required whether nickel or manganese base steel or substitute steels are used, but since only small amounts of either titanium or vanadium, or even zirconium, are required, it should be possible to avoid a shortage in the use of either or these elements.

When quenching and tempering are applicable, it may not be necessary to resort to alloy additions, and although

quenching is now being successfully applied to castings with such differences in section as would not have been possible a few years ago, limitations exist such as that alloying cannot be dispensed with. Production requirements usually demand that steel castings be made of compositions amenable to a normalising followed by a tempering treatment, without requiring full annealing or double normalising, unless a particularly heavy section demands double normalising to produce a good structure regardless of the composition used. Some increase in yield strength of normalised and tempered unalloyed steel may be attained by raising the carbon content, but this is usually attended by lowered ductility and impact resistance.

One type of steel, using a higher manganese than is desirable from the point of view of strategic substitution, but making good use of the ferrite strengthening effects of copper and silicon, contains approximately 1% silicon, 1% manganese, and 1.75% copper. This steel, in its annealed condition, has a tensile strength of 36.5 tons per sq. in. and a yield point of 29 tons per sq. in., which values, after normalising and precipitation hardening, increase to 47.5 and 39.0 tons per sq. in., respectively. This steel is a very fluid steel, and very complicated castings of it have shown up well in extremely severe service. Copper, by itself, goes part way towards giving good properties, but usually requires the help of either molybdenum, titanium, vanadium or zirconium. A steel containing 0.27% carbon, 0.58% manganese, 0.41% silicon, 1.21% copper, 0.20% molybdenum, and 0.05% titanium, after normalising at 870° C. and tempering at 200° C., had a tensile strength and yield point approximating to 44 tons and 30 tons per sq. in., respectively, while values approximating to 50 tons and 39 tons per sq. in. were obtained from the same steel after normalising at 870° C., tempering at 535° C., and precipitation hardening. This steel was prepared to evaluate the behaviour on single normalising of a copper-molybdenum steel of normal manganese content when suitably treated with titanium.

Because of the precipitation hardening effect of copper, normalised steels containing 0.75% to 1.5% copper become stronger and less ductile if tempered in the range 450° to 600° C. For greatest toughness, a stress-relieving annealing at 400° C., or softening temper at 620° to 675° C., is used; while for increased yield strength a 500° C. temper can be applied. There is a similar precipitation effect of molybdenum at 425° to 650° C. which opposes the softening effect of a temper after normalising, so that molybdenum containing steels are usually tempered at 650° to 675° C. In the usual small amount, 0.2% to 0.5%, in which molybdenum is added to cast steels this effect is not outstanding, but it does affect the choice of the tempering temperature. By choosing the right temperature the molybdenum steels can be improved in toughness and impact without much loss of yield strength.

The use of titanium or, as alternatives, vanadium or zirconium is essentially to obtain the best results with copper cast steels. Their function appears to be primarily in preventing grain coarsening of austenite on heating for normalising. In the case of titanium, and perhaps for the other grain refining elements also, there is a fixation of nitrogen, and the nitride particles may play a part in preventing grain coarsening.

\* *Metals and Alloys*, 1941, Vol 14, No. 5, pp. 704-711.

# Note on the Effect of Heat-treatment on the True Breaking Stress of Duralumin (6L1)\*

By W. H. Dearden, M.Sc.

*The note records some values of the so-called true breaking stress of Duralumin obtained from data based on autographically recorded load-extension diagrams. The number of test pieces available was severely limited, but results are given for Duralumin (a) as received, (b) annealed at 395° C., (c) aged at room temperature, and (d) aged at 145° C.*

THIS communication to the Institute of Metals is intended merely to place on record some data showing how various heat-treatments affect the so-called true breaking stress of Duralumin. In the literature there is no lack of information about the nominal ultimate, or maximum, stress of Duralumin and of other light alloys treated in all kinds of ways, but it is extraordinarily difficult to locate values of the true breaking stresses of these materials. For example, Teed's book<sup>1</sup> on "Duralumin and its Heat-Treatment," dealing with this alloy alone, and containing an extremely comprehensive collection of data about its properties, does not contain a single item concerning its true breaking stress.

To obtain the true breaking stress of a material it is necessary to know not only the nominal area of cross-section of the fracture but also the actual (minimum) load which will cause fracture on that section. As this load may be less than the maximum load (which is used to calculate the nominal maximum stress), it is not easy to determine unless an autographically recorded load-extension diagram is made during the test. And since, unfortunately, so many tensile tests are carried out without autographic records being made, the necessary information is rarely obtained.

The results given below are all based on diagrams obtained during tensile tests on a very limited number of Duralumin test pieces that were available. The latter were machined from 0.5-in. diameter Duralumin (6L1) rod containing:—

Copper	4.38
Magnesium	0.61
Manganese	0.64
Silicon	0.17
Iron	0.35

The tests were carried out in a small 3-ton machine of the spring-controlled compound-lever type operated by a variable-speed motor. The specimens were held in axial loading shackles, and the load, besides being recorded autographically, was also indicated visually by a pointer moving over a dial. Full details of the machine and of its accuracy can be obtained elsewhere.<sup>2</sup> The test pieces, of standard profile and 0.282 in. diameter, were provided with screwed ends to suit the machine.

Solution-treatment was carried out in a small vertical-tube furnace automatically controlled at  $495 \pm 5^\circ \text{C}$ . The test pieces were treated in batches of five, and were held in a suitable jig which maintained them vertical but free from any constraint. The centres of the gauge-lengths of the specimens lay, of course, in the same horizontal plane of the furnace, and the bulb of an N.P.L.-standardised, nitrogen-filled thermometer was also arranged to be in this plane. The reading of this thermometer was taken as the solution-treatment temperature.

Quenching was carried out by lifting the jig from the furnace and immediately plunging it and the specimens it carried vertically into a large volume of cold water.

In the subsequent tensile tests the maximum load and the breaking load as indicated on the dial of the machine were noted. As the dial was divided into degrees of arc, its readings were translated into tons by the use of a care-

fully prepared calibration chart. These readings were subsequently used as a check on the measurements made on the autographic diagrams. Loads determined from the dial and from the diagrams agreed very closely. Nevertheless, the results given are, as previously stated, based on the data provided by the latter.

A constant, rather slow, rate of straining was used throughout, and in consequence each test required about ten minutes to complete.

Immediately after breaking a specimen, diamond pyramid impressions under 30 kilogs. load were made on a surface previously prepared near one end. These hardness determinations were, in general, made merely to give an indication of the progress of the ageing process, and should not, therefore, be taken to represent accurately the hardness of the metal within the "gauge-length." The ends of a test piece, owing to the shortness of the uniform temperature zone in the furnace, were actually quenched from temperatures differing by some  $10^\circ$ – $15^\circ \text{C}$ . from that prevailing over the profiled part, which occupied the central 1.375 in. of an overall length of 4.625 in. The diameter of cross-section at fracture was determined in the usual way by fitting the fractured surfaces together and, with the necessary assistance, making measurements in two directions at right angles by means of a pointed micrometer.

Tables I–IV show the results obtained.

TABLE I.  
DURALUMIN IN THE "AS-RECEIVED" CONDITION.

	(a)	(b)
Diamond Pyramid Hardness, 30 kilog. load	116	114
Initial Area of Cross-section, in. <sup>2</sup>	0.0624	0.0629
Maximum Load, tons	1.93	1.93
Maximum Stress, tons/in. <sup>2</sup>	30.9	30.8
Final Area of Cross-section, in. <sup>2</sup>	0.0511	0.0511
Reduction of Area, %	18.1	18.1
Breaking Load, tons	1.93	1.93
Breaking Stress, tons/in. <sup>2</sup>	37.8	37.9

TABLE II.  
DURALUMIN ANNEALED BY HEATING AT  $390^\circ \text{C}$ . FOR 30 MINUTES AND FURNACE COOLING DURING 2 HOURS.

Diamond Pyramid Hardness, 30-kilog. load	62
Initial Area of Cross-section, in. <sup>2</sup>	0.0624
Maximum Load, tons	0.93
Maximum Stress, tons/in. <sup>2</sup>	14.9
Final Area of Cross-section, in. <sup>2</sup>	0.0343
Reduction of Area, %	45
Breaking Load, tons	0.81
Breaking Stress, tons/in. <sup>2</sup>	23.7

TABLE III.  
DURALUMIN SOLUTION-TREATED AT  $495 \pm 5^\circ \text{C}$ . FOR 3 HOURS COLD WATER QUENCHED. AGED AT ROOM TEMPERATURE.

Ageing Period, Hours.	D.P. Hardness (30-kilog. load).	Initial Area of Cross-section, in. <sup>2</sup>	Maximum Load, Tons.	Maximum Stress, Tons/in. <sup>2</sup>	Final Area of Cross-section, in. <sup>2</sup>	Reduction of Area, %	Breaking Load, Tons.	Breaking Stress, Tons/in. <sup>2</sup>
FIRST SERIES.								
0	73	0.0624	1.47	23.5	0.0471	24.5	1.46	31.0
4	90	0.0624	1.54	24.7	0.0426	31.7	1.45	34.0
22.5	114	0.0624	1.80	28.8	0.0456	26.9	1.74	38.1
96	122	0.0629	1.87	28.2	0.0464	26.2	1.78	38.4
168	116	0.0624	1.86	29.8	0.0437	30.0	1.77	40.5
SECOND SERIES.								
0	79	0.0629	1.42	22.6	0.0491	21.9	1.39	28.3
3.25	83	0.0629	1.45	23.0	0.0456	27.5	1.45	31.8
24	107	0.0624	1.80	28.8	0.0441	29.3	1.70	38.5
96	120	0.0624	1.89	30.3	0.0448	28.2	1.79	40.0
240	117	0.0624	1.90	30.4	0.0456	26.9	1.81	39.8

\* *J. Inst. Metals*, 1941, **67**, 357. (December.)

<sup>1</sup> P. L. Teed. "Duralumin and its Heat-treatment." London: 1937.

<sup>2</sup> J. L. M. Morrison. *Engineer*, 1934, 157, 626.

TABLE IV.  
DURALUMIN SOLUTION-TREATED AT  $495^{\circ} \pm 5^{\circ}$  C. FOR 3 HOURS.  
COLD WATER QUENCHED. AGED AT  $145^{\circ}$  C.

Ageing Period, Hours.	D.P. Hardness (30-kilogram load).	Initial Area of Cross-Section, in. <sup>2</sup>	Maximum Load, Tons.	Maximum Stress, Tons/in. <sup>2</sup>	Final Area of Cross-Section, in. <sup>2</sup>	Reduction of Area, %.	Breaking Load, Tons.	Breaking Stress, Tons/in. <sup>2</sup>
0	—	0.0624	1.44	23.1	0.0475	23.8	1.44	30.3
3	104	0.0624	1.70	27.2	0.0426	31.7	1.70	39.8
5	115	0.0624	1.68	26.9	0.0433	30.6	1.68	38.8
20	116	0.0629	1.70	27.0	0.0437	30.5	1.70	38.9
69	118	0.0624	1.74	27.9	0.0437	30.0	1.74	39.8

#### Notes.

(1) All except one of the specimens listed in Table III (room-temperature ageing) broke at an appreciably lower load than the maximum.

(2) In the cases of the "as-received" specimens (Table I) and of those listed in Table IV (aged at  $145^{\circ}$  C.) the maximum loads and the corresponding breaking loads were identical. Only one specimen of those aged at room-temperature behaved in the same way.

(3) The fracture of the annealed specimen was of the cup-and-cone type. Of the other specimens, four broke in an irregular manner, but thirteen failed by shearing on a plane inclined at about  $45^{\circ}$  to the axis of the test piece and passing through the necked-down portion.

(4) The maximum stress values achieved by ageing at room-temperatures are appreciably higher than those achieved by ageing at  $145^{\circ}$  C.

(5) The breaking stresses attained by the two methods of ageing are, on the contrary, in quite close agreement. In view, however, of the very limited number of tests made it is not possible to do more than draw attention to this feature of the results and suggest that it is a point worth further investigation when larger supplies of material are once more available.

## Specifications for Aluminium and Aluminium Alloy Products

THE considerable range and varieties of aluminium and aluminium-base alloys which are in commercial usage presents a problem to designers and engineers faced with the task of specifying materials, especially at the present time when many firms are engaged in the fabrication of products and materials with which they are not fully familiar. This classified summary of current D.T.D. and B.S. Specifications relating to aluminium and aluminium alloys will therefore be of great assistance. Compiled by the technical staff of the Northern Aluminium Co., Ltd., this booklet was first published in October, 1940. Since then, however, many specifications have been cancelled or modified by the authorities, and this new edition of the booklet includes all relevant alterations issued up to the end of November, 1941. With the object of simplifying the presentation of these changes, all specifications cancelled in recent years have been included in the numerical index of the new edition, with a note for the reason for cancellation.

The form of presentation remains unchanged in the new edition. A numerical list of the specifications is the basis of the index and is followed by the full range of British light alloys, classified according to the various forms in which each is produced—namely, ingot, sheet and strip, bars and sections, tubes, wire and rivets, forgings and castings. Under each of these headings are shown the appropriate D.T.D. and B.S. Specifications with the proprietary nomenclature and tables of chemical composition and mechanical properties. Finally, a tabulated summary of proprietary alloys in alphabetical order, showing the corresponding specifications and the forms of material to which they apply, is also given.

Copies of this publication may be obtained free of charge on application to the Research and Development Department of the Northern Aluminium Co., Ltd., Banbury, Oxfordshire.

## A System of Weld Dimensioning

In order that the design of any structure or machine be accurately reproduced and assembled, the shops must be provided with a set of detail drawings showing full particulars of each component part, and the assembly or erection department must be supplied with a drawing of the general arrangement showing the exact location of each member with respect to the remainder. The detail drawings must of course indicate how the separate parts are to be connected—that is, whether by riveting, bolting, or welding—as well as give particulars of the jointing material, unless these latter are described separately in the specification.

To avoid unnecessary waste of drawing office time and at the same time keep the drawings as clear as possible, the particulars relating to the assembly should preferably be as concise as possible, and for this reason each of the older methods of fabrication has evolved a standard code for imparting the necessary information. Though such codes may vary slightly in detail as between different classes of work, and even as between different works engaged in a similar type of construction, their fundamental principles remain unaltered and they are therefore universal in application. Thus in the case of riveting or bolting it is customary to give only the centres and to indicate by a conventional note that the rivets between these points are to be of certain diameter and pitch. All mention of shape of each of the different types of rivets or bolts would normally be entirely omitted in view of their standardisation with respect to the diameter, so that these particulars would only be necessary on rare occasions when some of the rivets or bolts must depart from the standard because of special considerations.

As a result of long-standing practice, this method of dimensioning riveted work is familiar in this country to both drawing offices and works alike, so that drawings thus dimensioned are conducive to economy in drawing office expenditure without leading to confusion or errors in the shops. The desirability of some form of system giving similar results in the parallel field of welded construction has been self-evident to engineers ever since the adoption of welding as a standard method of fabrication, and a number of proposals (including a British Standard) have been put forward in different countries with this object in view. Although some of these have been adopted as standard practice in the countries of their origin, none has yet found favour in Great Britain; it is for this reason that a system of weld dimensioning is put forward by Murex Welding Processes, Ltd., and it is hoped that it may fill the gap by virtue of the fact that it is entirely based on the system just described, which is already firmly established in the parallel field of riveting and bolting. This system is fully described in a booklet recently published, which presents the essential information to be recorded on the drawings and summarises it in the form of instructions to draughtsmen.

This is a very useful booklet on a subject which is in need of a more rigid form of specification. A very real effort has been made to base the system on sound principles, and the text matter is well supported by line drawings showing the various types of welds. It should be especially valuable in the present emergency. Copies may be obtained from Murex Welding Processes, Ltd., Waltham Cross, Herts.

## Mr. W. P. Pickering

Mr. W. B. Pickering recently completed fifty years' association with Messrs. Hadfields, Ltd., of Sheffield. To celebrate this important anniversary, Mr. P. B. Brown, chairman and managing director of the firm, invited his colleagues and their wives to a lunch, and advantage was taken to present to Mr. Pickering a set of three sterling silver fruit dishes.

# The Manufacture, Specification and Use of Phosphoric High-Duty Cast Irons

*The war demands the fullest use of home resources, and since the iron ores most abundant in this country are phosphoric, attention is directed to their use for engineering castings. It is shown that high-duty cast irons can be made containing phosphorus up to 0.5-0.6% without alloy additions, heat-treatment or special processing.*

**S**INCE the British Cast Iron Research Association was formed, in 1921, considerable advances have been made in the production of iron castings. It was formed at a time when the increasing demands of the engineer for improved castings necessitated more careful consideration of the many factors involved. Since that time the results of research have greatly facilitated the work of the foundrymen in meeting the more exacting demands, and it can be said that their application has done much to restore cast iron to a place of eminence among structural materials. The improvements obtained were by the use in part of imported ores, since the iron ores most abundantly found in the United Kingdom are phosphoric and considered by engineers to be unsuitable for making strong irons. With the aid of imported ores, however, many grades of pig iron, covering a wide range of compositions, were commercially available in all phosphorus contents from the low phosphorus hematite irons to those of over 1.5% phosphorus.

The war demands the fullest use of home resources, hence the necessity has arisen for the use of what can conveniently be called phosphoric high-duty irons, involving the adoption of the highest phosphorus content consistent with specified strengths and with service requirements. It is not surprising, therefore, that considerable interest was displayed at a recent meeting of the Lancashire Branch of the Institute of British Foundrymen, at which Mr. J. G. Pearce, Director of the British Cast Iron Research Association, presented a paper on the subject, based upon his report prepared for the Research Committee of the Institution of Mechanical Engineers on "High Duty Cast Irons for General Engineering Purposes."

Phosphoric irons are, comparatively, easily melted and poured, and hence are used in this country for the cheapest and commonest castings. Generally, engineers regard them as unsuitable for castings that require to be strong, but the weakness associated with phosphoric irons should be debited, at least in part, to factors other than phosphorus. It is well known that phosphoric irons are used in the highly developed light-casting industry; they have proved particularly suited to this class of work, but such castings are not normally submitted to engineering tests.

When the first national specifications for iron castings were drawn up in 1928, it was considered that the lowest grade, Grade C, of British Standard Specification No. 321, calling for 9 to 10 tons per sq. in. minimum ultimate tensile stress, could not be met by irons of the highest phosphorus content commercially available unless a measure of control were exercised on composition and melting practice. When such control is exercised, however, sound and successful engineering castings containing high percentages of phosphorus have been made for many years, and have been found to be of particular value in engine parts requiring resistance to wear. In an earlier report\* reference was made to irons containing 0.76% and 0.87% phosphorus meeting Grade 2 of British Standard Specification No. 786 (1938) (18 tons per sq. in. tensile), and hence qualifying as high-duty cast irons.

In recent years, however, there has been a definite movement in favour of the use of low-phosphorus irons for engineering purposes, and four factors have contributed to this. A marked development has taken place in high-duty

irons made from charges carrying high percentages of steel scrap and also of alloyed irons, both of which have tended towards low phosphorus contents. The rapidly growing automobile industry has required strong and dense castings, demanding, on account of their comparatively small size and thin section, a relatively high silicon content, with which a low phosphorus content is a necessary concomitant if soundness is to be assured. The development of continuous production systems, especially for large outputs of small castings, has encouraged the use of a standard composition low in phosphorus, adopted to ensure uniformity in foundry practice, although not technically necessary for the whole of the output. These tendencies have influenced practice in the production of larger castings, which can be made to yield a dense structure, free from shrinkage troubles in spite of a higher phosphorus content provided their silicon and carbon contents are suitably lowered.

## Founding Phosphoric Irons

No special difficulties arise and no additional precautions are required in founding high-duty irons with raised phosphorus contents. Foundries accustomed to the production of phosphoric irons not required to meet strength specifications will find attention to the following points essential, if strength specifications are to be successfully met. Melting practice should be adjusted to give higher melting temperatures, and a higher pouring temperature is required; larger ingates and risers are necessary, a more permeable moulding sand may be required, but additional venting may in some cases prove adequate; some form of control is an advantage, at least in the form of a wedge chill test; and, if possible, chemical, mechanical and microscopic tests should be carried out.

## The Effect of Phosphorus on Mechanical Properties

Within the range of grey irons, mechanical properties—static and dynamic—increase slightly as the section diminishes, and improve with diminishing silicon and carbon contents. The endurance limit in bending fatigue approaches one-half the ultimate tensile stress, and cast iron is relatively insensitive to notch effects and stress-raisers. The effect of dead annealing is to lower the static properties, but to improve the impact or shock resistance, although these changes diminish for irons of lower carbon and silicon contents. The effect of phosphorus on strength is outlined below, and the conclusions are derived both from results obtained in commercial practice from a wide variety of foundries and from experimental melts, both in crucible and cupola furnaces. They apply to plain cast irons made under controlled conditions, tested and used in the as-cast condition. They do not apply to specially processed, ladle-graphitised, alloyed, or heat-treated irons.

1. In melting ordinary mixtures of pig iron and scrap, the tensile, transverse, and fatigue strengths and transverse deflection normally increase uniformly as phosphorus increases, to a maximum of about 0.35% phosphorus. As the phosphorus increases beyond this point, these values uniformly decrease in such a way that the figures for irons containing 0.65% phosphorus are about equal to those obtained for phosphorus-free material. As the phosphorus increases beyond 0.65%, the figures continue to fall.

It is not practicable to give figures having general application to the change of properties taking place as a result of

\* First Report of Research Committee. Proceedings, Inst. Mec. Eng. 140, 163.

variation in phosphorus contents, because the properties of a given cast iron depend upon many other factors. In order to indicate the degree of magnitude of the change, the ultimate tensile stress may be expected to improve 2.5-5% for each 0.1% of phosphorus added to a non-phosphoric iron, up to a maximum of 0.35% phosphorus, and then to diminish at a similar rate. The ultimate transverse stress is usually slightly more erratic, and the change is rather less pronounced—about 2-4% higher for each 0.1% phosphorus added, up to the same maximum, followed by diminution at the same rate. The change in transverse deflection is of the order of 2-4%, the variation occurring in a similar way.

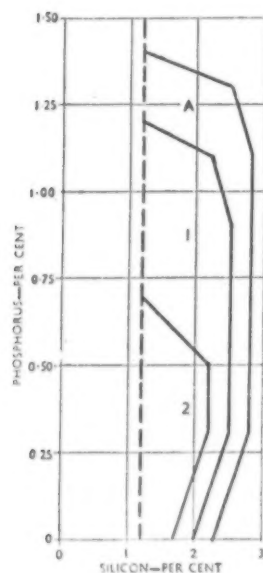


Fig. 1.  
Total carbon, 3.0-3.2%.

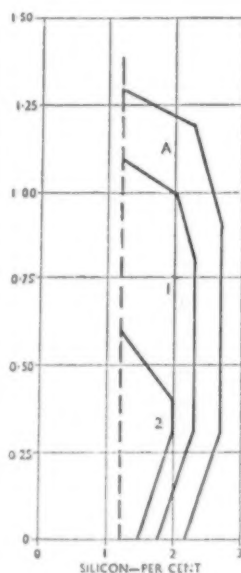


Fig. 2.  
Total carbon, 3.2-3.4%.

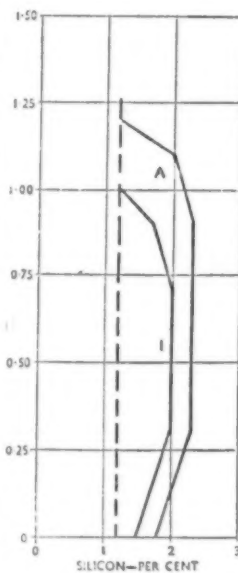


Fig. 3.  
Total carbon, 3.4-3.6%.

2. The Brinell hardness number of plain cast iron increases uniformly with increase in phosphorus content, and a rise of about 4 points may be expected for each 0.1% phosphorus added to non-phosphoric iron. Increased Brinell hardness normally indicates decreased machinability, but the effect of phosphorus on machinability is still an open question.

3. Impact or shock strength diminishes with increase in phosphorus content, and the shock strength of a phosphorus-free iron may be expected to be reduced by about 5% for each 0.1% of phosphorus added.

4. Resistance to wear is influenced by many factors, including structure and composition, soundness, the presence or absence of lubricant, and in particular the part against which the rubbing takes place. Minimum wear is obtained when the difference in hardness between the moving parts is a minimum. When the issue is not complicated by variation in other factors mentioned it is now generally agreed that, within the limits likely in engineering castings, resistance to wear increases with increasing phosphorus content.

5. Cast irons are sometimes annealed to facilitate machining, and there is a subsequent drop in the mechanical properties, but the drop in strength on annealing phosphoric irons is not so pronounced as in the case of non-phosphoric irons. Iron containing 1% phosphorus shows, on dead annealing, about one-half the drop in strength found in a low-phosphorus iron under similar treatment.

Tests on cast iron at elevated temperatures of sufficiently short duration to avoid creep and growth effects, show that within any limits to which structural engineering castings are likely to be submitted, the decrease in strength with temperature is small. These tests show that as temperature rises to about 200°-300° C. there is a slight fall in strength,

which is recovered at higher temperatures, so that at about 450°-500° C. the strength is approximately that at air temperature, after which the strength again falls fairly rapidly. This change is true for tensile strength, hardness, and impact strength. Phosphorus does not appreciably modify this, the strength falling slightly in phosphoric irons up to about 200°-300° C., then rising to air temperature level at 400°-500° C., after which the strength again falls.

Phosphorus does not materially alter the thermal expansion of a cast iron, but slightly lowers the thermal conductivity, the amount being about 0.5% for each 0.1% of phosphorus added.

### Use of Phosphoric Irons to Meet Specifications

British Standard Specifications No. 321 (1938) and No. 786 (1938) specify tensile and transverse strengths, the salient features of the scheduled requirements being given in the accompanying table. The strengths obtained in terms of composition—total carbon, silicon, and phosphorus—are given in Figs. 1, 2, and 3. Variations in manganese and sulphur met with in engineering castings do not influence these results, provided, as is usually the case, that the manganese content is adequate for the sulphur.

For convenience in use, each diagram refers to a specific range of total carbon contents: Fig. 1, 3.0-3.2%; Fig. 2, 3.2-3.4%; Fig. 3, 3.4-3.6%. Each diagram marks the specification which a given silicon and phosphorus content may be expected to meet for a given carbon range. Fig. 1 shows Grades 2, 1, and A. Fig. 2 shows Grades 2, 1 and A, the fields diminishing as the carbon content increases. Fig. 3 shows Grades 1 and A. Compositions outside the A field, but reasonably near to it, may be expected to

meet Grade C. The left-hand vertical boundary line in each diagram is dotted. It is not implied that irons having a lower silicon content than that indicated by this line

#### PROPERTIES OF PHOSPHORIC IRONS.

Requirements of B.S.S. No. 321 (1938) and No. 786 (1938).

The test-bars are cast respectively in overall lengths of 10 in., 15 in., 21 in., 22 in., and 27 in., and are tested transversely at spans 9 in., 12 in., 18 in., and 24 in. respectively.

U.T.S., minimum ultimate tensile stress.

T.R.S., minimum ultimate transverse (rupture) stress.

Test-bar, Dia. in.	Main Cross-sectional Thickness of Casting Represented, in.	Grade C of B.S.S. No. 321.			Grade A of B.S.S. No. 321.		
		U.T.S., Tons per Sq. in.	T.R.S., Tons per Sq. in.	De-flection, in.	U.T.S., Tons per Sq. in.	T.R.S., Tons per Sq. in.	De-flection, in.
0.6	Not exceeding 1/4 in. ...	10	19.9	0.06	12.5	25.1	0.07
0.875	Over 1/4 in. and not exceeding 1/2 in. ...	10	19.6	0.09	12	24.1	0.10
1.2	Over 1/2 in. and not exceeding 1 1/4 in. ...	9	18.9	0.13	11	23.1	0.15
1.6	Over 1 1/4 in. and not exceeding 1 3/4 in. ...	9	18.3	0.10	10.5	21.4	0.12
2.1	Over 1 3/4 in. ...	9	17.7	0.14	10	19.6	0.15
		Grade 1 of B.S.S. No. 786.			Grade 2 of B.S.S. No. 786.		
0.6	Not exceeding 1/4 in. ...	16	27.0	0.07	19	30	0.08
0.875	Over 1/4 in. and not exceeding 1/2 in. ...	15	25.9	0.11	18	28.9	0.12
1.2	Over 1/2 in. and not exceeding 1 1/4 in. ...	14	25.0	0.16	17	28	0.17
1.6	Over 1 1/4 in. and not exceeding 1 3/4 in. ...	13	24.0	0.13	16	27	0.14
2.1	Over 1 3/4 in. ...	12.5	23.6	0.17	15	26.1	0.19
		Grade 3 of B.S.S. No. 786.			Grade 4 of B.S.S. No. 786.		
0.6	Not exceeding 1/4 in. ...	23	34	0.09	26	41	0.10
0.875	Over 1/4 in. and not exceeding 1/2 in. ...	22	33	0.13	25	39	0.14
1.2	Over 1/2 in. and not exceeding 1 1/4 in. ...	20	31	0.18	23	37	0.23
1.6	Over 1 1/4 in. and not exceeding 1 3/4 in. ...	19	30	0.16	22	35	0.18
2.1	Over 1 3/4 in. ...	18	29.1	0.21	21	33	0.24

cannot or do not meet the appropriate specifications; the bulk of the evidence available relates to silicon contents above that represented by the dotted line.

Figs. 1 and 2 show that high-duty cast irons capable of

being classified as Grade 2 of British Standard Specification No. 786 (1938) can be made containing phosphorus up to 0.5 to 0.6% without alloy additions, heat-treatment, or special processing.

## Electrodeposition and the War

**T**HIS war, which has been forced upon mankind, is not being fought out so much between man and man as between machines. Tanks, aircraft, sea-craft are all playing major parts in achieving success, but machines of this type are also victims of that other war—against corrosion. It is in this latter direction that electrolytic processes are contributing to the war effort, and electroplaters are diverting their energies and skill from decorative finishes in order that they can produce finishes of direct use to the war effort. The subject was recently discussed at a meeting of the Electrodepositors' Technical Society with Dr. S. Wernick in the chair, at which Mr. H. Marston reviewed briefly the war-time applications of various electrodeposition processes, with special reference to cadmium.

The use of cadmium has grown in popularity as a protective material, especially as a rustproof undercoat for metal finishes. All the solutions in practical use for electroplating are of the cyanide type; these yield very satisfactory results. They contain the double cyanide of cadmium and sodium, with additions of free cyanide and alkali and some addition agent. Mr. Marston gave details of simple shop tests and a short account of cadmium-bath troubles and remedies.

For testing the cadmium metal in the bath, the method recommended is to take a 20 c.c. bath sample in a 50 c.c. 7 in.  $\times$  1 in. measuring cylinder, graduated in cubic centimetres, add 10 c.c. of sodium-sulphide solution (S.G. 1.037), shake and fill up to 50 c.c. with water. Allow to stand 12 to 24 hours, and every 2 c.c. of the precipitate is approximately equal to 1 oz. of metal per gallon of bath. This method is suitable as a check when the bath is balanced. To test the bath for free cyanide, a 10 c.c. sample is filtered, diluted to 200 c.c. with distilled water, and 5 c.c. of 10% potassium-iodide solution added; it is titrated with silver-nitrate solution (8.5 g./litre) until a faint permanent turbidity is reached. Then the number of cubic centimetres of silver nitrate divided by 10 equals the ounces per gallon of free cyanide.

In testing for caustic soda, a 5 c.c. sample is taken and diluted to 100 c.c., boiled and 25 c.c. of saturated barium-nitrate solution added. The precipitate is allowed to settle, and the mixture is filtered hot through double Whatman No. 44. The filtrate is cooled, and N/10 silver nitrate is added until faint turbidity is shown. Then 0.5 c.c. phenolphthalein solution is added and N/10 hydrochloric acid run in until colour is discharged. If  $x$  c.c. of N/10 hydrochloric acid are used for the 5 c.c. sample, then  $x \times 0.128$  equals ounces per gallon of caustic soda. In

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this estimation, it is pointed out, boiling water, i.e., carbon-dioxide free, must be used.

In dealing with bath troubles, Mr. Marston referred to blistering and rough deposits which are often due to high currents. To rectify this trouble, pickle in 10% hot sulphuric acid, swill and dry off. Scratch-brush or polish to produce original surface, and replating with correct current. Dark patches, or a smoky appearance, after using a high current, are probably due to an excess of free cyanide and can be reduced by small additions of cadmium carbonate.

Although Mr. Marston gave particular attention to cadmium-plating, he was able to review briefly the war-

time applications of several electrodeposition processes. He mentioned, for instance, that silver deposits up to 0.005 in. were being produced on contactor tips; they were used for maintaining conductivity between make-and-break switches. Anodes for photo-electric cells are silver-coated. Aircraft panels are fitted with silver-plated articles. Using the sodium-stannate solution, components are electro-tinned, which are subsequently inserted into a mould prior to casting in iron. It is claimed that the tin coating helps the wrought iron or steel insert to amalgamate with the cast iron and reduces the possibility of blow-holes in the casting adjacent to the inserts. Parts requiring protection against marine atmospheric corrosion are also being tinplated. Limit gauges supplied by the Ministries for armament work are coated with chromium, as are punches, dies and small tools. While lead is still being applied to the terminals of accumulators to prevent corrosion of the latter, a new use has been found for this metal in the plating of impellers used in the fume-extraction plant.

In the interesting discussion which took place Dr. Wernick commented upon the wide field of war-time applications in electrodeposition covered by Mr. Marston, and stated that owing to supply difficulties there was a definite tendency to replace cadmium plating by zinc-plating.

## Bessemer Gold Medal, 1942

THE Council of the Iron and Steel Institute announce that the Bessemer Gold Medal for 1942 has been awarded to Mr. Eugene G. Grace, President of the Bethlehem Steel Co., and an outstanding member of the iron and steel industries in the United States of America.

The decision was telegraphed to Mr. Grace on New Year's Day by Mr. K. Headlam-Morley, Secretary of the Institute, in the following words:—"I am directed by Mr. John Craig, President, and the Council of the Iron and Steel Institute to inform you that the Institute award to you the Bessemer Medal for 1942, in recognition of your valuable services to the iron and steel industries and in appreciation of all you have done to foster technical, scientific and industrial collaboration between the industries in Great Britain and the United States. Cordial congratulations."

The following telegram, dispatched by Mr. Grace on January 3, was received in reply:—"Please convey to the President and Council of the Iron and Steel Institute my deepest appreciation of the signal honour they have conferred upon me by the award of the Bessemer Medal for 1942. In accepting this award it would be selfish on my part not to recognise that the services attributed to me by the Institute's generous citation reflect as well the team work and co-operative efforts of my associates in the Bethlehem Steel Co. and the American steel industry as a whole. The receiving of this award, the highest honour bestowable to one in the world's steel industry *in absentia* and for services rendered during the greatest crisis in history, further emphasises its significance. Again my sincerest thanks and a resolve jointly with you to dedicate all to accomplish a just peace throughout the world."

## Group Ablution in Industry

ALL modern large engineering establishments are provided with a complete equipment of wash-basins and other lavatory accommodation, often including showers and baths, which require a large amount of warm water. During recent years great advances have been made in this field, and especially for dealing with conditions of hundreds of people wanting to wash more or less at the same time.

The old method of running cold and very hot water out of two taps into a wash-basin not only represents a considerable waste of time, but is also very inefficient because of the loss of water. A much more efficient method is to supply warm water at the necessary temperature, such as 105° to 110° F., through a single tap to each basin or wash-trough, also in the form of a spray instead of a "solid" jet.

There is much to be said for the use of washing troughs of fire-clay, porcelain, cast iron, or steel, or zinc-lined wood, instead of small separate basins. Still more efficient are the new designs of very large circular wash-basins at which half a dozen people can wash at one time, and in all cases in running clean water.

For the supply of the large amount of warm water necessary, of great interest are the "Leonard-Thermostatic" mixers, available in three standard types, made by Walker, Crossweller and Co., Ltd. By the use of these mixers very hot water at any desired temperature can be mixed continuously and blended water discharged at the desired temperature, which is maintained automatically at a constant figure irrespective of fluctuations in the temperature, and the pressure at the cold and hot inlets. The temperature required is adjusted merely by operating an indicating handle. Incidentally, for showers and baths, the usual temperature is 105° F., but for special cases, such as decontamination and first-aid centres for dealing with gas-poisoning cases, the best temperature is approximately 95° F., which often applies also in hospitals. In general, these types of mixer, available in a considerable range of sizes, are on the same principle—that is, the use of a powerful thermostatic bimetal strip coil, which, whilst being very powerful, is extremely sensitive in movement to slight change in the temperature.

Accordingly, the desired figure for the blended warm water is maintained automatically because the thermostatic bimetal coil operates inlet valves for the hot water and the cold water, and adjusts these almost instantaneously, opening or closing accordingly one or the other to keep the temperature constant. The two metals used in making the bimetal coil are non-corrodible, and the whole apparatus is small and compact in size, and is easily fixed on a wall or in any other convenient position, whilst the whole design is extremely simple in spite of its sensitiveness and accuracy, characteristic of thermostatic coil control in general.

## The Influence of Stress on the Corrosion Pitting of Steel in Distilled Water

THE lowering of the fatigue limit, due to stress corrosion of steel in distilled water, was discussed by McAdam\* in 1931. At that time, however, no investigation had been made of the forms and sizes of the corrosion pits and their correlation with the cyclic stresses applied during corrosion. Later the specimens that had been used were made available for such investigation. A recent paper by McAdam and Geil† gives the results of the investigation, and correlates the forms and sizes of the corrosion pits with the resultant lowering of the fatigue limit.

In this latter investigation specimens previously corroded in distilled water, with or without stress, were examined on surfaces and on longitudinal sections to determine the form, size and distribution of the corrosion pits as affected by stress during corrosion. The pits formed in distilled

water are smaller and shallower than those formed in well water. Pits formed in distilled water, moreover, tend to occur in clusters, whereas this distribution is seldom found after corrosion in well water.

Cyclic stress tends to increase the size and relative depth of the corrosion pits. Steady stress, if sufficiently high, accelerates corrosion pitting in distilled water, but not in well water. At sufficiently high stress and cycle frequency, crevices or fissures project from the initially rounded pits, stress corrosion in distilled water tends to form crevices, rather than fissures.

The form, size, and distribution of the corrosion pits have been correlated with the lowering of the fatigue limit and with the forms of diagrams of various types. The lowering of the fatigue limit is much slower by corrosion in distilled water than by corrosion in well water. Difference is due to the difference in size and relative depth of the pits. Diagrams representing constant total and net damage due to corrosion in distilled water differ greatly from those representing damage in well water.

The authors discuss briefly the process of stress corrosion in distilled water. The accelerating effect of steady stress on corrosion in distilled water probably is due to an increase of the solution pressure in regions of local plastic deformation around corrosion pits. They also discuss the practical importance of the fact that steady stress, under some corrosion conditions, may accelerate the corrosion pitting of steel.

## Notes on an X-Ray Investigation into Cold-rolled Magnesium Alloy Sheet

SOME years ago, while engaged in a general survey of the application of X-ray crystal analysis to industrial problems, Dr. L. Frommer undertook a brief X-ray investigation into questions connected with the rolling of magnesium alloy sheet. The object of this research was primarily to find out whether the directional mechanical properties observed in cold-rolled magnesium alloy sheet could be explained from features revealed in X-ray diffraction patterns. In view of extensive investigations into the rolling of magnesium and its alloys, recently reported by Jones and Powell<sup>1</sup> and by Thomas,<sup>2</sup> Dr. Frommer has submitted notes\* in his findings in his above work.

The original material used was Dow metal sheet (aluminium 4.66, manganese 0.32%). Specimens were cold-rolled in one direction to extensions ranging from 2 to 50%, and subjected, in the cold-rolled state and after annealing at 350° C. for 1 hour, to tensile tests parallel and transverse to the direction of rolling, and to X-ray investigation.

The results of the tensile tests show that above 5% cold extension, the tensile properties exhibit a strong directionality in the as-rolled state; in particular the ductility is much lower parallel to the rolling direction than transverse to it. Annealing greatly diminishes this directionality.

X-ray patterns obtained with Mo-radiation transmitted through specimens in the three main directions show, in all cases, a strongly preferred orientation approaching a fibre structure, the hexagonal axes preferring positions approximately normal to the sheet surface, with deviations up to about  $\pm 30^\circ$ . In specimens cold-rolled to higher degrees, the range of deviation parallel to the rolling direction is markedly greater than the range transverse to the rolling direction, in both the as-rolled and the annealed state. The occurrence of this disparity does not correspond with that of the mechanical directionality, and it is therefore not the primary cause of the latter.

Glancing-reflection exposures were taken with Fe-K radiation in a setting which gave patterns enabling the (002) reflection spots of the individual grains to be recognised separately. These patterns indicate that, in cold-rolling, the basal planes of the original grains suffer curving and buckling preferentially around axes transverse to the direction of rolling.

\* D. J. McAdam, Jr., "Influence of Water Composition on Stress Corrosion," *Proceedings, Am. Soc. Test. Mat.*, **31**, Part II, 1931, 259-278.

† D. J. McAdam, Jr., and G. W. Geil, *Annual Convention of Am. Soc. Metals*, October, 1941.

<sup>1</sup> W. R. D. Jones and L. Powell, *J. Inst. Metals*, 1940, **66**, 331; and 1941, **67**, 153.

<sup>2</sup> D. E. Thomas, *J. Inst. Metals* 1941, **67**, 173.

<sup>3</sup> L. Frommer, *J. Inst. Metals*, 1941, **67**, 361.

# Substitute Solders

*Tests carried out on a large number of alloys, with a view to the selection of substitute solders, show that alloys containing reduced amounts of tin will be found more acceptable than tin-free solders.*

**N**O one application, with the single exception of tinplate, uses more tin than does the manufacture of solders. With the growing possibility of curtailment of supplies, it is appropriate that an effort should be made to find satisfactory substitutes for an application of tin, which is vital both to peace-time industry and to the manufacture of war materials. The results, therefore, of an examination by F. N. Rhines and W. A. Anderson\* of some 75 alloys, which are representative of virtually all of the types of compositions which have been proposed as soft solders, excepting those intended only for the joining of aluminium, is of interest.

Since the claims made for special properties in these alloys are necessarily based upon a wide variety of tests, it was found advisable to re-examine the entire group with a series of standardised tests. The 75 alloys examined included pure tin, pure lead, tin-lead alloys in various proportions, tin-lead-antimony, tin-lead-bismuth, tin-lead-cadmium, tin-lead-bismuth-cadmium, tin-cadmium-zinc, lead-cadmium, cadmium-zinc alloys and other alloys containing lead or lead and tin with silver, nickel, mercury, arsenic or phosphorus. One pound lots of each alloy were prepared from pure metals melted together in clay-graphite crucibles, and cast in convenient-shaped bars in a horizontal iron mould.

The following physical tests were carried out on all the alloys:—

- (1) Tensile strength of a soldered joint 0.005 in. thick between copper bars.
- (2) Shear strength of a soldered joint 0.005 in. thick between copper bars.
- (3) The capillary rise in inches between  $\frac{1}{4}$  in. copper rods.
- (4) The spread of a drop of solder 0.1 c.c. in volume on a horizontal copper surface under flux.
- (5) The rate of corrosion of the solder itself in a standard 3% sodium-chloride salt spray after 98 days, and after 203 days.

Liquidus and solidus temperatures were obtained from published results on the various alloys, and where these were not available they were determined directly on the solders used in the tests. Soldering procedure was standardised by making all joints at a temperature of 60° C. above the liquidus temperature of the solder, and capillary and spread of drop tests were also made at this temperature. In addition to those tests and the physical tests, several qualitative observations of interest to users of solders on the surface appearance, and ease of tinning of the various solders, were also made, together with the use for which each type of solder was most suitable.

Among the alloys tested were an extensive series of binary tin-lead compositions, which were included in order to provide a basis for comparing the properties of substitute solders with the commonly used tin-rich compositions. In making the comparison, it was found convenient to consider first those alloys in which the tin content was simply reduced, and second, those alloys from which tin had been entirely eliminated. Among the metals used as partial substitutes for tin were antimony, cadmium, bismuth, zinc and mercury.

It has been found from the use of lead-tin-antimony alloys through a long period of years that antimony cannot be substituted for tin beyond 7% of the tin content

without damage to some of the useful qualities of solder. The alloys containing up to 7% antimony are satisfactory for general use, and for some purposes are superior to the binary alloys of lead and tin because of the greater strength at elevated temperatures and a slower creep rate. Cadmium has been shown to be a substitute for tin in rather larger proportions than antimony, partly because alloys higher in lead can be used when cadmium is present. This is done with some sacrifice of good working qualities, and with a little loss in strength of the joints formed. The tests carried out have shown that alloys containing 65% to 80% lead and 10% to 26% cadmium are most promising, and within this range cadmium can be substituted directly for tin with no serious loss except in tensile strength, which is often unimportant.

Lead-tin-cadmium alloys show a desirable rise in the capillary test, but are subject to rather severe oxidation, particularly when the tin content is below 10%, and as there is a tendency for such oxide to be trapped in the joint, low temperatures are necessary in using these alloys. Where such solders can be used, a considerable saving of tin can be effected at slight inconvenience and some increase in cost.

Lead-tin-bismuth alloys, while more difficult to handle than standard solders, have been shown capable of producing acceptable joints, but their principal disadvantages lie in their low-melting points, which give rise to low strengths. Lower lead contents must be used with bismuth, so that the saving of tin is not directly proportional to the bismuth added. Several combinations containing both bismuth and cadmium were also tested and gave superior shear strengths, but such alloys contained an unduly large proportion of tin. Owing to the cost of bismuth, solders containing it cannot be used economically except under extraordinary circumstances. The addition of zinc to lead-tin solders is shown to be unsuccessful, a large amount of dross being formed during working if the zinc content is at all high. The presence of zinc also causes a marked decrease in the corrosion resistance. Mercury has only been used for solders of low-melting point, but is never added in large quantities. When present it allows of the use of distinctly larger lead contents, and can, therefore, be regarded as a tin solder substitute.

While solders made without the use of tin have shown less promising properties than those containing reduced quantities of tin, there are several alloys which deserve special notice. Alloys based on lead and cadmium produce joints of acceptable strength, can be handled satisfactorily if precautions are taken against oxidation—that is, if working temperatures are kept as low as possible and care exercised in fluxing.

The tests carried out, however, show that all those alloys melt at rather higher temperatures than do the tin-lead-cadmium alloys, and special techniques by which oxidation is altogether avoided without the uses of flux have had to be developed for handling such alloys in special applications. Cadmium-zinc alloys exhibit many interesting properties, in that they make joints of satisfactory strength and are not subjected to severe oxidation similar to the lead-cadmium series. An alloy containing 40% cadmium, 60% zinc gave the highest shear stress of any composition tested, a strength 50% greater than the best tin-lead solder. The chief disadvantage of cadmium-zinc alloys is the difficulty experienced in tinning joints. Lead-silver alloys

\* *Metals and Alloys*, 1941, Vol. 14, No. 5, pp. 712-717.

are shown to give joints of good strength, but are unattractive in appearance. Such alloys have high-working temperatures, good strength at elevated temperatures, have been used in a number of applications, and appear well suited for substitute solders.

In general, the tests carried out show that not one of the alloys tested can be expected to serve all the purposes now served by the tin-base alloys, and that a group of alloys covering the various needs must be used. It appears, on the whole, that the alloys containing reduced amounts of tin rather than tin-free solders will be found most acceptable for soldering copper. Among those the tin-lead-cadmium combinations appear most promising, and some compositions of outstanding merit are indicated. Of alloys containing no tin, the lead-cadmium and lead-silver series are most attractive. Cadmium-zinc alloys and tin-lead-bismuth alloys should also prove of use for some special applications. In the selection of a substitute for tin, care must be taken, however, that a metal which might equally become scarce is not used.

### Hot-Tinning "Difficult" Mild Steel

DIFFICULTIES encountered in hot-tinning certain mild-steel articles are discussed by W. E. Hoare and H. Plummer, in a booklet recently published by the Tin Research Institute, in which they suggest means by which these difficulties may be overcome and sound tin coatings produced on the steels. The discussion is divided into three sections.

The first outlines methods which may be employed in a tinning shop to avoid irregular and discontinuous coatings on articles and components fabricated from so-called "difficult" mild steels, and may be regarded as practical suggestions arising out of the scientific investigations described in detail in the other two sections. Irregular coatings are sometimes obtained from certain batches of mild steel, whether in the form of sheet, strip, or fabricated articles, when prepared for hot-tinning by normal procedures. The trouble is usually seen as "de-wetting" of the tin coating, sometimes described as "streakiness" or "runs." When this occurs, and more thorough degreasing or extension of pickling time does not overcome it, it is stated that mechanical treatment, heat-treatment, or a deep-pickling procedure will rectify the trouble.

A detailed treatment of methods available for rectifying "difficult" steels is given in Section II. The procedures, have their particular applications and as modifications of technique may be necessary in certain cases, details of the experimental and theoretical basis for suggestions outlined in the first section will be found valuable.

The reasons why such "difficult" mild steel surfaces arise in practice are discussed in Section III, and means are suggested whereby the production of steels of inferior tinning quality may be avoided. The difficulties are ascribed to the formation of adherent lacquer-like films arising from the rolling and drawing lubricants and coolants being partially decomposed in contact with the metal surface by heat and possibly oxidation and pressure.

Methods of producing and fabricating mild steel of good tinning quality can be selected so that this trouble is avoided. Mention is made of the pronounced effects on tinning quality when steel is cold-worked with certain lubricants and annealed without an intermediate degreasing operation. In this connection it is noteworthy that in cold-reduction tinplate mills, where consistent production of good tinning quality stock is a pre-requisite, an electro-cleaning operation between the cold-reduction mill and the annealing operation is standard practice.

This booklet contains much valuable information; it may be obtained on application to the Tin Research Institute, Fraser Road, Greenford, Middlesex. It is issued as Publication No. 107.

### Magnesium Dust Extraction

THE possibility of dust explosion in plants handling powdered metals is generally recognised, and the need for protection against this hazard is of increasing importance in view of the rapid growth of powder metallurgy. The simple fact that metal dusts are explosive should be justification enough for the adoption of all known precautions to prevent ignitions wherever such dusts or powders are produced, processed or handled, and producers and users of metal powders should co-operate in making available to the industry experiences or data that will contribute to the development of safe practices with a view to the elimination or reduction of this hazard. An effort in this direction has been made by F. A. Hughes and Co., Ltd., by the publication of a booklet which deals specially with magnesium dust extraction.

For some reason, it is frequently assumed that the risk of explosion with magnesium dust is greater than with other metal, yet scores of tons of magnesium powder have been produced without serious accident, and large-scale grinding operations in this and other countries are undertaken daily without undue risk. Certain precautions are, however, necessary, and in their absence explosions are likely to occur.

Some of these precautions are not the less important for being obvious. Magnesium dust ranges in size from finest powder to  $\frac{1}{32}$  in., and its lower explosive limit is approximately 70 mgs. per cub. ft. Experience shows that whereas the first explosion may be relatively harmless, the dust raised thereby will tend to greatly increase the quantities of dangerous dust/air mixture, and so cause a second and more serious explosion. Hence the need for scrupulous cleanliness and good ventilation in the workshop, which should also be dry. The walls must be smooth and devoid of all ledges where dust might accumulate. If pipes, shelves and corners difficult of access cannot be avoided, they must be swept regularly—vacuum cleaners *not* being used for this purpose. The sweepings should be placed in steel bins and removed from the premises. Floors adjacent to machines should be smooth and devoid of open cracks. Every source of ignition, including smoking, must be forbidden.

It is recommended that the clothing of operators, in addition to being made of a texture to which dust will not adhere, should be impregnated with a special fireproofing mixture. A "Faspos" No. 3 solution, obtainable from Imperial Chemical Industries, Ltd., has been found effective for this purpose.

However, apart from these general precautions, further measures involving the use of special dust extraction plant are necessary to keep the dust out of the room atmosphere. The main feature of all such equipment, which, in general, resembles that used with other metals, is the drenching of the magnesium dust as close as possible to the point where it is produced—usually the grinding point. It should be noted, in passing, that although this method of precipitation is the safest and easiest it is not the sole method, and that in at least one process magnesium dust is exhausted without the use of water in large-scale power production—a further proof that it is not exceptionally explosive.

This booklet, with the aid of line illustrations, describes the type of equipment most widely recommended, but it also includes useful information for those firms that prefer to use existing equipment, or equipment of their own design. Copies are available on application to F. A. Hughes and Co., Ltd., Abbey House, Baker Street, London, N.W.1.

### Surface Preparation for Painting Aluminium Alloys on Aircraft.

The test methods and results obtained by the testing of two processes for treating aluminium alloy surfaces prior to painting are given in a report.\* The Alumilite and Alok processes were submitted to exhaustive tests to fit them for use for aircraft surfaces.

\* *Jour. Aeronautical Sciences: Review Sect.*, 9, 1941, p. 17.

# Austenitic and Martensitic Special-Duty Cast Irons

*Special-duty cast irons are in greater demand as a result of war conditions, and in order to provide information regarding the properties of austenitic and martensitic cast irons a very useful report has been prepared, which is here summarised. These materials are not only being used as substitutes for other materials, but are finding new applications.*

**A**S a consequence of the war, a demand has arisen among engineers and users for further information on special-duty irons, which are being used both as substitutes for other materials in urgent demand and for new applications arising out of the unusual conditions now prevailing. To meet this demand, Mr. J. G. Pearce, Director of the British Cast Iron Research Association, has prepared several reports for the Research Committee of the Institution of Mechanical Engineers. The more recent of these reports deals with austenitic and martensitic special-duty cast irons; it is admirably written and contains very full information on cast irons in general and special cast irons in particular, and should be invaluable to engineers seeking materials for special purposes.

The report is conveniently divided into three parts, the first giving introductory information relating to the various types of cast iron and their classification. The author points out that the old visual distinction between pig or cast irons as grey, white and mottled is no longer valid, although the large bulk of engineering cast irons are grey and machinable, being structurally pearlitic, while white irons are hard and not ordinarily machinable. All cast irons can be conveniently grouped with reference to the presence and form of graphite, and with reference to the structure of the matrix in which the graphite is distributed. So far as the matrix is concerned, six structural groups can be identified, and can therefore be recognised. To indicate the effect of structure on properties, the range of Brinell hardness for each group is given as follows:—

1. Ferritic .....	110—140
2. Ferritic-pearlitic .....	140—180
3. Pearlitic .....	180—350
4. Austenitic .....	140—150 (160—220 with Cr.)
5. Martensitic { Soft .....	350—450
{ Hard .....	550—700
6. Cementitic .....	280—550

From the engineer's or user's point of view, the pearlitic group is by far the largest and most important, and includes the bulk of castings made, and this group can with advantage be sub-divided on a basis of mechanical properties and in accordance with national specifications. Several possible methods of division are available, for example, on the basis of phosphorus content, as between low-, medium-, and high-phosphorus irons; or on the use or otherwise of special processing methods, such as ladle graphitisation ("inoculation") or heat-treatment. On the whole, however, the most satisfactory sub-division is on a basis of strength, and in accordance with existing national specifications. Such a basis gives results not dissimilar from those obtained by other methods.

## Austenitic Cast Irons

The second part of the report is intended primarily as a guide to the engineering properties of the austenitic cast irons, in order that engineers may use them to the fullest extent justified by their properties. The data presented are drawn from authoritative sources, and are those of interest to the user rather than the maker, to the engineer rather than the metallurgist.

Austenitic cast irons may be regarded as bearing the same relation to ordinary cast irons as some of the stainless steels bear to the ordinary steels. Although more expensive, both in raw materials and manufacture, the austenitic cast irons have properties which mark them off as different

from all other cast irons, particularly in their softness and ductility; high resistance to wear, erosion, corrosion and heat; non-magnetism and relatively high electrical resistance; low thermal conductivity and high thermal expansion. Their mechanical properties compare with those of a good engineering cast iron, but their softness and toughness make them readily machinable. They are readily welded. They are not susceptible to ordinary heat-treatment—i.e., quenching and tempering—but they can be annealed at low temperatures with advantage. They can be cast white if required, and a simple thermal treatment, such as annealing at 950° C. for 30 mins. yields a metal with 2–3% elongation in the cold. While the founding of these irons presents special problems, these can be overcome, and the smallest castings can be, and are, successfully made in austenitic irons, down to  $\frac{1}{8}$  in. section; but if thin sections should be hard, they can be softened by the treatment given above. They melt at about 1,150° C., a figure similar to that of the non-phosphoric cast irons, and have a specific gravity of 7.2–7.6.

Austenitic cast irons are made by the addition of certain alloys, in defined amounts, to cast irons. Of these additions, nickel is the most important, and is the only one, so far as is known, alone capable of rendering an iron austenitic without at the same time increasing the carbide content and hence giving an undesirable high proportion of eutectic in the structure. Cast irons of about 3.5% carbon and over 1% silicon become fully austenitic with an addition of 20% or more of nickel. The addition of certain other elements enables desired modifications of properties to be made, or, alternatively, the amount of nickel to be reduced. Thus, copper can be used to some extent to replace nickel, and chromium is a convenient means of increasing both the hardness and heat resistance. Irons can be made austenitic by the use of manganese (only half as much manganese as nickel being required), but only at the expense of an undesirably high proportion of carbide. The maximum manganese content for austenitic irons in commercial use is about 5%, but even these are of inferior resistance to corrosion.

In general, properties are discussed in relation to the well-established types of austenitic cast iron, on which most of the work available has been done. These are known as "Nomag," "Niresist," and "Nicrosilal."

Nomag, introduced primarily as a non-magnetic iron, normally contains 10% nickel and 5% manganese. Niresist is a nickel-copper-chromium iron, introduced primarily as a corrosion-resisting iron, but generally useful wherever austenitic irons are suitable, and the normal composition is 14% nickel, 7% copper, and 2% chromium. Nicrosilal is a nickel-chromium-silicon iron, introduced primarily as a heat-resisting iron, but also generally useful. Wide variations in these compositions can be made to suit special requirements.

The data given on mechanical properties include transverse strength and deflexion; tensile strength and elongation; elastic modulus; impact and shock strength; fatigue strength; creep strength; hardness; strength and rigidity at elevated temperatures. Data are also given on the erosion-, abrasion-, and wear-resistance of austenitic cast irons; their machinability; weldability; resistance

to corrosion and resistance to heat. Physical properties data are also included.

This part concludes with an appendix giving the major engineering applications of austenitic cast irons and, since these will have a special interest for many readers, they are included in the following:—

**Non-magnetic Castings.**—Generator end covers; rotor end spiders; alternator castings; transformer insulator bushings; transformer covers; switchgear castings; bus-bar chambers; instrument and meter cases and frames; frames for magnetic chucks and bodies; magnetic separator drum ends and pulleys; lifting-magnet cases; welding machine parts.

**Electrical Resistance Castings.**—Resistance grids, liquid rheostat electrodes.

**Engine, Pump and Boiler Castings.**—Internal combustion engine combustion chambers, piston crowns, piston ring carriers; gas compressor liners, pistons, piston rings, valves and seatings; pump bodies and impellers; ventilator impellers, rotors, and gears; super-heater tube spaces; automobile cylinder liners, piston rings, valve seatings exhaust manifolds.

**Furnace Parts and Heat-resisting Castings.**—Firebars; stoker links; furnace grids, plates, arches, hearth skids, shells, roller frames and rollers; sintering furnace rabblers, arms, shoes; firedoors, recuperators, elbows; end spindles for continuous moving hearths; annealing cradles; enamelling pettets; oil burner flame cones; soot blower pipes and nozzles; clinker dams; wire annealing pots; cyanide pots; regenerator boxes; carburising boxes; dies for die-casting; electric hot plates.

**Corrosion-resisting Castings.**—Centrifugal pump bodies, impellers, eye rings and sleeves; recuperating pump cylinders, pistons, piston rings, rams, valve chests; valves and seats; reaction vessels and stirrers; drying cylinders; suction filter drum frames and spiders; centrifuge frames; rolls and rollers; hoppers, chutes, pans for handling chemicals; mixer bowls, paddles, dough dividers, choppers and mincers in food manufacture; cylinder mould spiders and blow pit pipes in paper manufacture; oil refinery bubble caps and trays; instrument beds and frames; tar stills; sewage plant pipe, valves, pumps; salt baths; chemical evaporators, retorts and filters; sulphuric digester pipe lines; sea-water pipe lines; laboratory drain pipes.

**High-expansion Castings.**—Valve sleeves for internal combustion engines; internal chills for foundries.

**Low-expansion Castings.**—Dies; strip mill continuous gauge castings.

### Martensitic Cast Irons

Martensitic cast irons, which are discussed in the third part, have been developed in recent years on account of the resistance to wear, erosion, and abrasion associated with the martensitic structure, and they are applied in engineering accordingly. These cast irons may be produced by heat-treatment of an ordinary engineering pearlitic iron; or they may be specially produced and so treated that either of two varieties can be obtained. In one such variety the eutectic filling surrounding the primary grains is allowed to solidify white (cementitic), and in the other it is allowed to solidify grey (graphitic). There are thus two main classes of the martensitic cast irons which are generally made as such; they may be respectively described as "white" and "grey" in character, the former being the harder of the two. The "grey" variety can be made martensitic in the condition as cast, or alternatively a martensitic structure can be produced in it by suitable heat-treatment.

While a great deal of experimental work has been done on the production of the less hard, or grey, variety of martensitic iron, the greater industrial need has been for the harder variety, and it is for this type that the bulk of the information recorded is available. The type has

various trade names, but is best known as "Nihard." The essential feature of the composition is about 4.5% nickel and 1.5% chromium; the other elements resemble those in chill-cast irons, the silicon being relatively low. For the highest hardness the carbon content is raised to a maximum, and for the highest strength it is lowered to a minimum; while in general the carbon and silicon contents are higher and in small castings.

Nihard irons are not usually required for their resistance to corrosion or heat, but for their resistance to wear, erosion and abrasion. They do not offer any increase in ductility or elongation over the ordinary engineering grey irons.

Date and information on transverse, tensile and impact strength are given; on machinability, hard facing by welding on, and resistance to wear, together with data on the physical properties of these martensitic irons. In this part also is included an appendix giving the applications of these irons. These are reproduced in the following:—

(1) **Grey Martensitic Cast Iron (Martensitic as Cast).**—Ash-handling pump impellers and wear plates; automobile cylinder liners; grinding machine drums and rests; pump cylinder liners; scraper blades.

(2) **Grey Martensitic Cast Iron (Martensitic Structure Developed by Heat-treatment).**—Air-cooled motor-cycle cylinders; automobile cylinder liners; automobile and aero-engine valve guides; cams for textile machinery; cut gears; die inserts; Diesel engine liners; jig bushings; jigs and fixtures; metal-working draw dies, light blanking dies, forming dies, and small press dies.

(3) **Martensitic White Cast Iron (Nihard).**—Ash discharge doors, pump bodies and impellers; trough conveyer pipes, elbows and chutes; ball mill trunnions; ball and rod mill liners, feeder lips and scoops; beater tips; brake blocks; brick mould liners; cable car pulleys; cement mill roll head rings; centreless grinder blades; chute plates for ash, coal, coke, ore; clay pipe dies; coal-breeze pit pumps; coffee grinder plates and burrs; coke-quenching car sides and bottoms; concrete pump liners and plungers; conveyer plates, skidder bars, sprockets; crusher roll shells, rolls, small, for brick-making, etc., jaws; dredger pump bodies and impellers; dust collecting valves; fan blades for pulverised coal; feed screws; gravel pipes; grinding machine rests, mill balls, pan bottoms, plates; grizzly discs; mill guides; mixer arms; muller tyres; muller wheels; mine car wheels; plough points and shares; pug knives; pulveriser bull rings, hammer and plates; pump rams; rolls for metal working; sand and shot blast nozzles, table segments, tumbling barrel liners and baffle plates; sand mixer ploughs; sand slinger cups and wear plates; shot-slinger baffles and blades; stamp mill heads and shoes; scraper blades.

### Non-Metallic Substitute for Aluminium

A non-metallic material designed to replace aluminium in many important defence uses has been revealed by the United States Rubber Co.\* Defence production orders for this new material, designated simply as Formula C-102, are now being negotiated. The formula, except for small amounts of rubber, is made of non-strategic materials which are farm grown. The substance is fibrous and rubber-like, and its ingredients are organic materials. It has been approved in tests by the Army, Navy and Bureau of Aeronautics. Its tensile strength is 60% of that of aluminium, but it is one-third lighter than that metal. Additional qualities include an absence of crystallisation under vibration, and freedom from corrosion and pin-hole formations. Despite penetration by machine-gun bullets, the material does not open up in the flowering typical of aluminium sheets. C-102 is fabricated in sheets, is formed under heat and pressure. It is now made in panels less than  $\frac{3}{8}$  in. thick and up to 60 in. wide.

\* *Iron Age*, 1941, 16, p. 51.

# Oil-Retaining Bronze Bearings

*Efficient lubrication of bearings that are inaccessible has resulted in the development of oil-retaining bronze bearings. Reference is made to this method of continuous lubrication.*

ONE of the most important fields for the modern oil-retaining bronze bearing, which runs noiselessly and efficiently for years without lubrication, is machine tools. This includes not only the many different bearings in turret and capstan lathes, planing machines, grinders, and milling machines, including the electric drive, but also hand tools, such as electric drills and hammers. Apart from elimination of the troublesome, dirty and costly method of continually supplying oil, there is the great advantage of continuous efficient lubrication of bearings and other parts that are almost inaccessible. Consequently, some of the most important applications, apart from machine tools and electric motors, include a wide range of intricate mechanical contrivances, such as electric razors, piano players and cinema organs, and electric clocks, in addition to motor vehicles.

In this field are the British Bound Brook Bearing Co., with their "Compo H" oil-retaining bronze. This has the chemical composition 88.0% copper, 9.7% tin, 1.4% graphite, and 0.9% other material, and is made by diepressing the pure powdered metals, made electrolytically. A very wide range of standard sizes and shapes of bearings and bushes and other parts, such as collars, rings, plates, ball seats, plugs, hinges, and washers is available. The resulting bronze is of great strength, having a s.g. of 5.8-6.5 and a crushing load of 70,000 lb. per sq. in. In spite of this, however, the structure is micro-cellular—that is, crystals with minute spaces between—and on immersion

in oil absorbs 25-30% by volume. This oil forms a permanent film at the surface of the metal and when the pressure and temperature varies, as in a bearing, exudes or recedes accordingly, giving continuous self-lubrication, which lasts for years.

All these standard bearings, several hundred in number, up to 2½ in. diameter and 2½ in. long, and other parts, are supplied with a mirror surface ready for use, made to extremely accurate dimensions, easily within plus or minus 0.001 in., and even closer limits if necessary. An interesting point is that the actual amount of oil required to provide a permanent lubricating film for an indefinite period—that is, many years—is only a small percentage of the total oil in the metal. For example, in one detailed test, a ¼ h.p. motor fitted with these bearings was run continuously for 10,000 hours, equal to more than 1,000,000 revolutions, about 5 years' normal operation, and the amount of oil used was 5.8 grams for the front bearing and 3.8 grams for the rear bearing, while there is no sign of wear. In practice, the oil in the bearings will last as long as the machine.

Incidentally, one indication of the value of this method in ensuring efficient lubrication of bearings that are inaccessible as regards other methods is vacuum cleaners with speeds up to 18,000 r.p.m. involved, whilst one well-known make of cinema organ has over 200 different bearings of this type which otherwise would be impossible to lubricate.

## Cladding of Aluminium-Copper Magnesium Alloy

RECENT developments which have been made in connection with the process of cladding strong aluminium-copper-magnesium alloys with aluminium and corrosion-resistant aluminium alloys, as a means of protection, are reviewed by Kostron.\* The developments were aimed at improving the behaviour of the clad sheet in order to meet the demands of the aircraft industry for material of this type, which could be used without any additional surface protection, and also to prevent diffusion of copper through the cladding during heat-treatment.

The behaviour of the cladding material is discussed to begin with. When using clad materials without any surface protection, even a small amount of corrosion cannot be tolerated, as this seriously detracts from the appearance of the material, even though the mechanical properties remain unchanged. This fact more or less rules out the use of aluminium alloys as cladding.

The hardness of the cladding material, as measured by the Brinell test, does not give a true valuation of its resistance to scratching and abrasion, tending to exaggerate differences between pure aluminium and the copper-free aluminium alloys used for cladding.

In considering the protection afforded to the strong alloy by the cladding material, the electrochemical protection of cut edges and parts of the alloy exposed through the cladding is mentioned. An interesting point which is brought out is that the clad material as a whole has been shown to possess better resistance to corrosion than even the cladding material—e.g., aluminium itself. This is due to the fact that if pitting occurs in the cladding material

the depth of the pits will be limited to the thickness of the cladding, and such pits when formed will not detract seriously from the strength of the material as a whole.

Diffusion of copper into the cladding material during solution heat-treatment and subsequent precipitation heat-treatment is then discussed. Diffusion occurs along the grain boundaries of the aluminium to begin with, and after the copper has reached the surface the interior of the grains will be attacked, preferentially under corrosive conditions. Further diffusion may lead to the copper diffusing through the grains as well, and the cladding will then cease to be an effective corrosion protection. Aluminium-magnesium-silicon alloys cannot be used as a cladding if the material is to be subjected to precipitation heat-treatment, as they will develop a tendency to inter-crystalline corrosion as the result of such treatment.

Experiments have shown that the addition of 0.5% or more of manganese to the pure aluminium cladding prevents diffusion of copper along grain boundaries. Diffusion takes place through the cladding as a whole, and its progress is much slower than in the case of pure aluminium.

Another way of avoiding diffusion is to subject the alloy at an early stage during rolling, preferably before the cladding material is applied, to heat-treatment designed to distribute and refine the Al<sub>2</sub>Cu constituent. This enables the finished material to be completely solution heat-treated in a very much shorter time than if this preliminary heat-treatment were omitted.

In conclusion, the possibility of using multiple cladding layers is considered. The best results are obtainable by cladding with aluminium and aluminium-manganese alloy, and then again with aluminium, in that order.

\* H. Kostron. *Aluminium*, 23, 1941, pp. 195-204. (Light Metals Bulletin, Jan. 9, 1942.)

## The Rototherm Rotostat

THE value of an efficient device that will indicate automatically, say by a bell or hooter, when temperatures reach danger point, does not require emphasis, and for this reason of considerable interest is the new "Rototherm Rotostat," operating on the bimetal

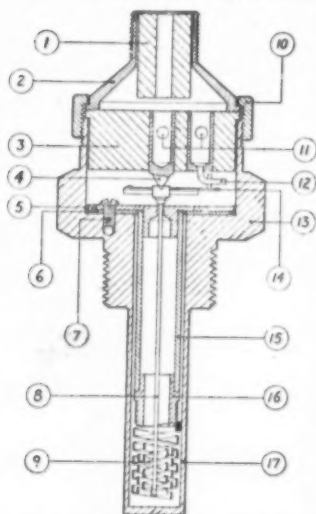


Fig. 1.—Vertical section of the "Rototherm Rotostat."

1. Rubber protection sleeve.
2. Protection cap.
3. Contact block.
4. Pivot contact pin.
5. Setting plate.
6. Dial.
7. Setting screw.
8. System shaft.
9. Rototherm bi-metal multi-coil.
10. Knurled ring.
11. Terminal set-screws.
12. Fixed contact.
13. Body of Rotostat.
14. Moving contact.
15. Inner stem.
16. System holder.
17. Outer stem.

dial thermometers. In the stem at the bottom is a small, compact, multiple-helical coil consisting of a thin and very narrow strip formed of bimetal, that is two alloys of greatly differing properties as regards expansion and contraction, made in the usual manner by pressing together with original billets when in the heated plastic condition. A bimetal coil expands or contracts in pronounced fashion with great accuracy in direct proportion to the temperature, and in making the coil a long length of the strip is wound in the form of a series of short, continuous coils of different diameter and, alternately, opposite "pitch" one inside the other. This difficult operation is carried out by the use of a patent precision machine, by means of which the length of ribbon, is formed into a short inner coil, then another coil of the reverse pitch is wound over the inner coil, followed by a third coil of the same pitch as the first, and so on, which neutralises all the horizontal movement that would result with the use of a single coil, and cause inaccurate readings.

The expansion and contraction of the coil in the base of the stem operates a light vertical rod or system shaft, which, in turn, operates a moving contact arm, instead of a pointer over a dial, as in the firm's bimetal coil thermometers. When the temperature reaches danger point the moving arm touches a fixed contact connected to a source of current and completes the circuit, so that the alarm comes in to action.

helical-coil principle. The arrangement consists of a small and compact all-metal casing, with a screw top and a stem of desired length, inserted in the bearing at the desired point. Several standard temperature ranges are available, and by means of an adjustable setting plate the instrument is set to give a warning at any desired temperature. When the latter is reached an electrical contact is made, and according to one arrangement a three-terminal bell is used, so that when the contact is made the instrument itself cuts out and the current is left full on the bell, which goes on ringing until reset by a push-button, cord or similar device. For operating a large bell or hooter a relay is necessary, so as to bring into action a more powerful current.

The instrument is a production of the British Rototherm Co., Ltd., and operates on the same principle as the firm's range of

## Radiant Heat in Industry

THAT the bottlenecks of production are being gradually reduced, there is no doubt. The announcement that the R.A.F. has now reached parity with the Luftwaffe is one of the most recent indications of that.

Though many industrial operations can be speeded up by mechanical means and others by the sheer concentration of human effort, there are still some processes, mostly those which rely on physical and chemical reaction, that demand some fundamental change in procedure before appreciable progress can be achieved. The drying of the various kinds of paints and varnishes used in industry has always presented a special problem in peace time, and in a time like the present this problem has, naturally, become much more urgent.

With the solution of this problem and, of course, the removal of another bottleneck to industry, as the ultimate goal, the Research Laboratories of the General Electric Co., Ltd., have continued pre-war investigations into the application of radiant heat from incandescent filament lamps to paint drying and kindred problems. Naturally, these investigations have been biased towards those applications that have a special significance in relation to the war effort.

Though it is perhaps a little early for a complete explanation of the mechanics of drying by radiant heat (that must await post-war research), the results achieved to date show that the system is essentially practical. The convenience, economy and flexibility of the system are firmly established and the reduction in heating and drying times which it has so far effected are, in some instances, most remarkable. The high rate of heat transfer which can be obtained from radiant sources is, no doubt, the factor which distinguishes it fundamentally from convection methods of drying.

The salient features of drying or heating by radiant heat are:—

- (a) The drying period is extremely short: much shorter in many cases than is achieved by enclosed convection ovens.
- (b) Objects to be dried can be more quickly raised to the correct temperature than by any other method.
- (c) Because of the shortened drying time, the space which has to be devoted to the drying process can frequently be substantially reduced. An important point in factories seeking for means of increasing output.
- (d) Since the heating of the materials or parts is practically independent of the air temperature, free circulation of air can be effected, resulting in the rapid dispersal of the paint's volatile constituents, and the elimination of the gas pockets which may be so troublesome in enclosed ovens.
- (e) Many industrial processes necessitate the special heating of articles, such as preheating at one temperature and baking at another, or the heating of different parts of the same article at different rates. Where these conditions exist, the flexibility of the radiant heating system has many times demonstrated its superiority over convection ovens.
- (f) Heating a convection oven from its cold state at starting or maintaining the temperature before a new charge can be inserted requires a considerable amount of energy. With radiant heating, the full heating effect is obtained immediately the current to the lamps is switched on.

The radiant energy, or infra-red rays from incandescent filament lamps, can be controlled and directed much in the same way that light rays are controlled—i.e., by means of suitably designed lamps and reflectors—and to this end the G.E.C. has produced special lamps and reflecting equipment, possessing the required characteristics.

### WANTED

Copies of Metallurgia for May and October, 1938.—G. E. STECHERT & CO., 2, Star Yard, London, W.C.2.

